RETRIEVABILITY CONSIDERATIONS AND THEIR IMPACT ON THE DESIGN OF VERTICAL EMPLACEMENT AND RETRIEVAL EQUIPMENT FOR A REPOSITORY IN SALT

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ABSTRACT

The current design concept for the disposal of nuclear high level waste packages in a repository in salt is based on the emplacement of individual packages in vertical boreholes in the underground mine floor. A key requirement is that the waste packages be capable of being retrieved during the last 26 years of the 76-year repository operating period. The unique design considerations relating to the retrieval of waste packages emplaced in bedded salt are presented in this paper. The information is based on the experience developed during the design of vertical emplacement and retrieval equipment in support of the Sandia Defense High Level Waste experiments at the Waste Isolation Pilot Plant. Also included are the impact of retrievability on the design of the equipment, the special salt cutting technology that was developed for this application, and a description of the equipment.

INTRODUCTION

The vertical emplacement concept for a geologic repository in salt involves the placement of waste packages in vertical boreholes with the space above and around the package filled with crushed salt. A single waste package is emplaced in each borehole. A key requirement is that the waste packages be capable of being retrieved during the last 26 years of the projected 76-year repository operating period.

The creep of the rock salt, accelerated by the thermal output from the waste packages, can cause the salt to close around the package and displace it from its original location. The new position of the waste package has therefore to be located and the salt overburden removed by the retrieval equipment to gain access to the package. The waste package is then removed by overcoring or, if the package includes a heavy overpack, the option is available for cutting out the overpack lid and removing the internal canister.

The unique design considerations that were applied to the first-of-a-kind emplacement and retrieval equipment in support of the Sandia Defense High-Level Waste (DHLW) experiments at the Waste Isolation Pilot Plant (WIPP) in New Mexico are presented in this paper. Many of the issues and considerations involving retrieval in a full-scale repository in salt will be the same as those required to be addressed at WIPP. However, it is recognized that satisfactory, safe, and effective methods and equipment for an experimental program may not necessarily represent the best approach to accomplishing similar operations in a full-scale repository. The WIPP experience provides a unique insight into the repository interfaces and problems that can be meaningfully applied to the design of full-scale repository equipment.

The paper addresses the design requirements that were applied to the design of the DHLW Vertical Emplacement and Retrieval Equipment, and describes the salient features of the equipment design.

DESIGN REQUIREMENTS

The design requirements for the DHLW Vertical Emplacement and Retrieval Equipment are summarized below:

Interface Requirements

The equipment has to:

- Interface with the cask loading room equipment in the WIPP surface facility.
- Fit into the waste hoist conveyance, as a unit or as dismantled subassemblies, without exceeding its payload limit.
- Have overall dimensions that permit transportation through the underground access drifts.
- Be compatible with the experimental area interfaces shown in Fig. 1.

Functional Requirements

The equipment has to:

- Be designed to emplace and retrieve the DHLW packages shown in Fig. 2.
- Be designed to retrieve all the emplaced waste packages during a period of 1 to 25 years after emplacement. The waste packages may be tilted up to 10° to the vertical. Their location will be known to ±5 cm and ±2° in any direction.
- Be designed to give a maximum surface dose rate of 100 mRem/hr.
- Be designed to operate underground in a ventilated area in the presence of salt dust and humidity. The ambient temperature in the emplacement rooms will be 25°C to 50°C.

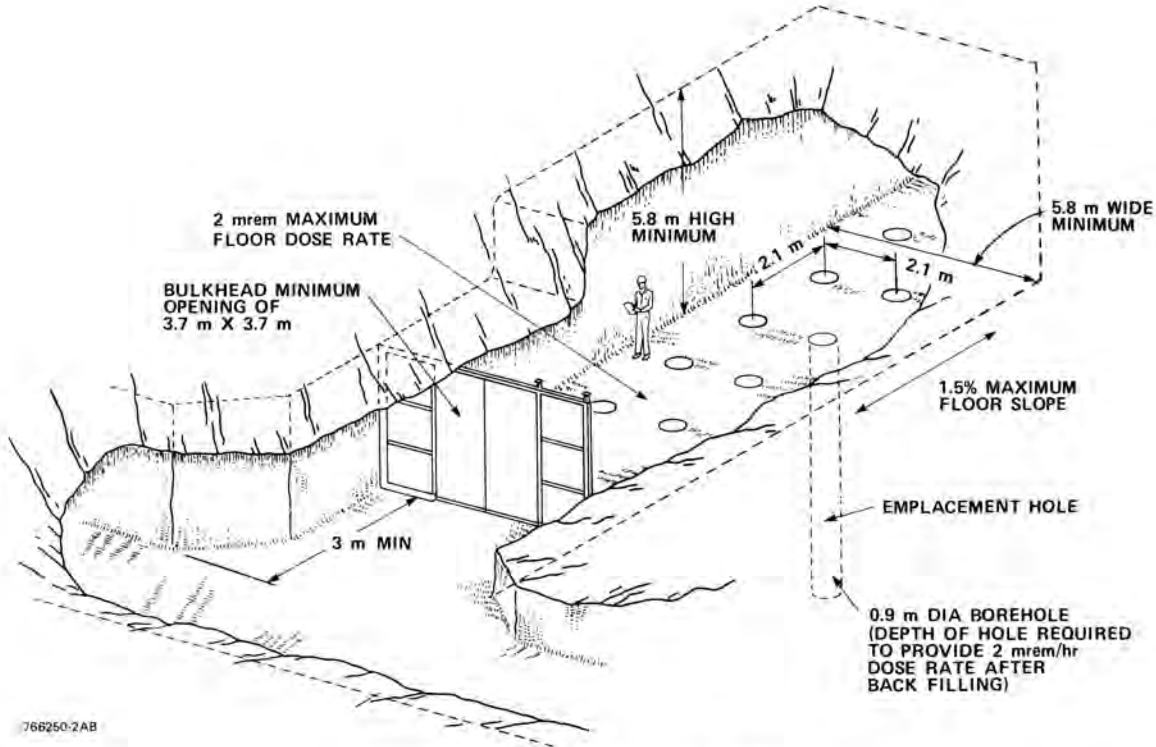

Fig. 1. DHLW Experimental Area.

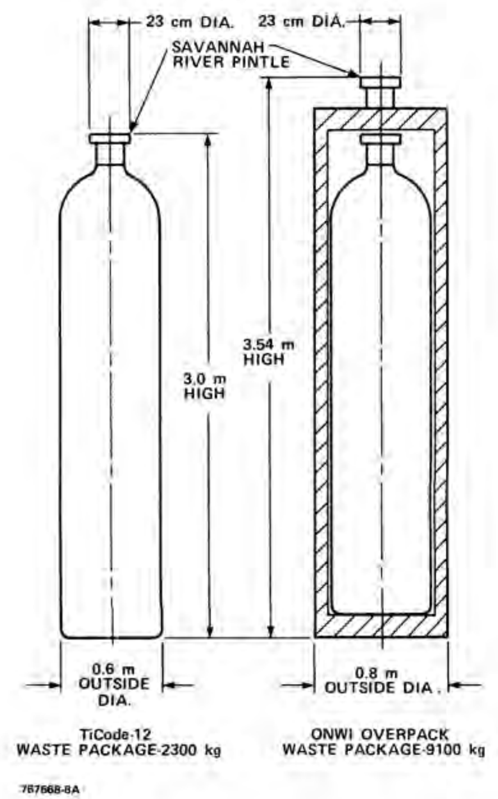

Fig. 2. Defense High Level Waste Packages.

RETRIEVABILITY CONSIDERATIONS AND DESIGN APPROACH

The capability for retrievability of the waste packages during a 25 year period following their emplacement represents the most significant consideration in the design of the emplacement and retrieval equipment. As will be evident, the sophistication and complexity of the equipment are dictated by the required capability for retrieval.

The major considerations relating to retrievability are:

- Salt creep and its effect on the location of the waste package.
- Location of the buried waste package
- Need for preserving waste package surface corrosion data.
- Backfill consistency
- Thermal and radiation environment

Salt Creep

The phenomenon of creep is of particular significance in salt. Creep data recorded at WIPP and analytical predictions show that total vertical closure of the emplacement rooms could occur within 18 years based on an average areal thermal loading of 18 W/m^2. Unheated rooms and access drifts have estimated closure rates of over 15 cm/year.

The effect of salt creep on the location and tilt of the waste package is not predictable with any degree of precision. Several scenarios are possible and they are discussed below.

- The salt around the waste package could creep uniformly and not have a significant effect on the waste package location or tilt, or cause compaction of the backfill around the waste package. This condition is possible during the early years of the retrieval period.
- The salt creep would not have a significant effect on waste package location or tilt, but could compact the backfill around the package.
- The salt creep could be significant enough to cause compaction of the backfill and tilt the waste package.
- The floor heave associated with significant salt creep could cause the waste package to be raised from its original position with or without tilt. As the emplacement room will be remined to restore it to the minimum envelope dimensions prior to retrieval, the net effect of the floor heave is to bring the waste package closer to the surface of the mine floor.

The approach that was used for the equipment design was to provide the capability for retrieving waste packages that could be tilted up to 10° to the vertical, but with the assumption that waste package tilts in excess of 5° would be accompanied by significant floor heave that would bring the package closer to the floor. This approach was based on a review of the best available information on creep behavior in the WIPP experimental area.

The retrievability of the TiCode-12 waste package as a function of borehole diameter and hole depth is shown in Fig. 3. The data, based on a simple analysis of the waste package and borehole geometries, shows that a 1.22 m minimum diameter borehole would permit the retrieval of a waste package tilted 5° from a depth of 2.44 m, while a package tilted 10° can be retrieved from a depth of 1.22 m. It is seen that the main advantage of taking credit for floor heave is that smaller retrieval equipment is required. This was an important consideration in view of the limited operating room available in the WIPP experimental area.

1.22 m DIA BORE HOLE	
HOLE DEPTH (m)	MAX ANGLE*
1.22	10.20°
1.52	8.14°
1.83	6.78°
2.13	5.81°
2.44	5.08°
1.52 m DIA BORE HOLE	
HOLE DEPTH (m)	MAX ANGLE*
1.22	10.20°
1.52	12.20°
1.83	15.70°
2.13	13.40°
2.44	11.70°

*WITH A RADIAL LOCATION TOLERANCE OF 5 cm

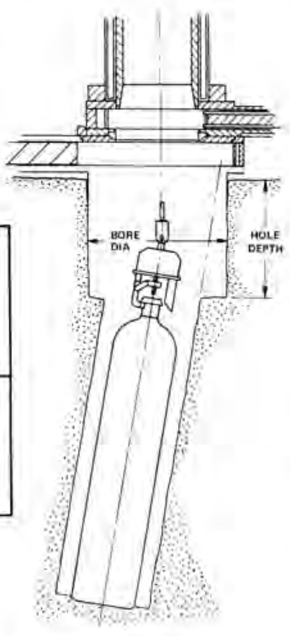

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Fig. 3. Waste Package Retrievability as a Function of Tilt Angle.

Location of the Buried Waste Packages

A determination of the precise location of the waste package at retrieval is important because of the potential for the package shifting as a result of salt creep and floor heave. The degree of uncertainty in locating the waste package has a direct effect on the degree of complexity in the retrieval equipment design. Methods are being currently developed for the location of waste packages buried in salt, including the use of radar technology. The locating uncertainties with these techniques are estimated to be ±5 cm and ±2° of tilt in any direction. Hence, the retrieval equipment has to be capable of accommodating this uncertainty.

Need for Preserving Waste Package Surface Corrosion Data

A key objective of the Sandia DHLW experiments at WIPP is to obtain corrosion data on waste package materials. Thus it was important to preserve the surface condition of the retrieved waste packages to the maximum extent possible by minimizing abrasion with the retrieval equipment. Combined with the uncertainties in locating the waste package, this requirement imposed a severe challenge in terms of aligning the salt cutting equipment and overcoring the waste package.

Backfill Consistency

The backfill around the waste package may have a consistency varying from virgin salt to loose particles. It can also have regions with moisture content that form a halo around the package. The expected consistency of the backfill has been likened to fresh concrete that has not hardened. The salt cutting and overcoring equipment has to be able to cut through this material and remove it from the borehole without clogging the material removal system.

Thermal and Radiation Environment

Preliminary estimates of the ambient temperatures in the emplacement rooms show that forced-convection cooling will be required to maintain room temperatures low enough for operating personnel to enter and operate the retrieval equipment. Ambient temperatures can remain high even after weeks of forced cooling. Similarly, radiation exposure calculations show that the background radiation in the experimental area is a major contributor to the total operator dose. Therefore, it is important to design the retrieval equipment to minimize hands-on operations and transportation and handling time within the rooms.

The approach taken to the design of the retrieval equipment involved:

- Development of innovative salt cutting technology to cut the borehole, overcore the waste package, and remove the salt and backfill debris.

- Design of a Shielded Work Enclosure (with salt cutting tools) that was used between the borehole cutting and overcoring operations to clean the salt and backfill from around the waste package pintle and head area, and to precisely locate the position and tilt of the waste package. This enabled the overcoring equipment to be positioned accurately and ensured the retrieval of the waste package with minimum danger of damaging it.
- Design of a radio remote controlled straddle carrier-type Underground Equipment Transporter for transporting, handling, and positioning the retrieval equipment one at a time in the emplacement room. This minimized the need for prolonged periods of operating personnel presence in the experimental area.

The design requirements that were applied to the Vertical Emplacement and Retrieval Equipment, and a description of the equipment are given in the following sections.

VERTICAL EMPLACEMENT AND RETRIEVAL EQUIPMENT DESCRIPTION

The Vertical Emplacement and Retrieval Equipment consists of the following:

- Shielded Cask Assembly (including the Cask Grapple).
- Underground Equipment Transporter
- Floor Shield Valve
- Backfill Hopper
- Borehole Cutter
- Annulus Cutter
- Vacuum System
- Shielded Work Enclosure

Table I indicates whether these equipment are used for emplacement and/or retrieval operations.

TABLE I

Emplacement and Retrieval Equipment

Equipment	Operations for Which Used	
	Emplacement	Retrieval
Shielded Cask Assembly	X	X
Underground Equipment Transporter	X	X
Floor Shield Valve	X	X
Backfill Equipment	X	
Borehole Cutter		X
Annulus Cutter		X
Vacuum System		X
Shielded Work Enclosure		X

Shielded Cask Assembly

The Shielded Cask Assembly provides shielding for the waste package during its transfer between the surface facility and the underground experimental area. The cask is designed to hold either the TiCode-12 waste package or the ONWI overpack waste package.

The major design considerations for the Shielded Cask Assembly were:

- Compatibility with surface facility equipment.
- Compactness for transportation through the access drifts.
- Flexibility for carrying both TiCode-12 and ONWI waste packages.

The Shielded Cask Assembly, shown in Fig. 4, represents one of the largest components used in the emplacement and retrieval system. It is 1.4 m wide and 2.2 m long at the valve end and has an overall height of 3.9 m in the vertical position. It weighs 33,000 kg. The cask body and the shield gate are of double-walled carbon steel construction filled with cast lead. The shield gate is actuated by an electro-mechanical drive system with provision for a manual override.

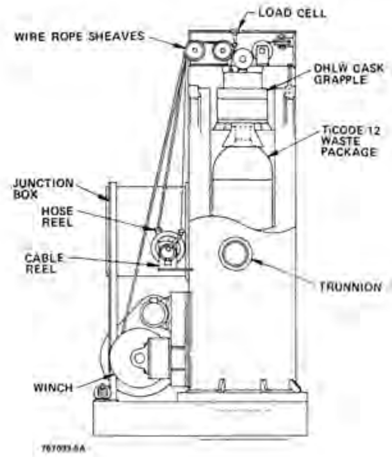

Fig. 4. Shielded Cask Assembly.

Flexibility for accommodating the TiCode-12 waste package or the larger ONWI waste package is provided by a removable carbon steel insert sleeve installed in the cask. The insert also provides the additional shielding required for the TiCode-12 waste package.

The upper end of the cask incorporates a grapple which can be locked in position to be a part of the cask containment boundary when not in use. The grapple is released for transferring the waste package to and from the cask. The travel of the grapple is controlled by an electric motor-operated wire rope winch that is mounted on the cask. Additional cable and hose reels are provided for the management of power and signal cabling to the grapple and for supplying compressed air for its actuation. The cask has a pair of lifting trunnions and a smaller pair of pivoting trunnions that are used for rotating the cask between the horizontal and vertical positions in the surface facility.

Cask Grapple

The Cask Grapple transfers the waste package between the Shielded Cask Assembly and the borehole or surface facility equipment. While numerous grapple designs have been developed in the past for a variety of nuclear applications, none of them were found to meet the requirements for the current application. A simple and rather novel pneumatically operated grapple was therefore developed for this purpose. The important design considerations were:

- Need for the grapple to guide itself over a waste package pintle that could be tilted up to 10° to the vertical during retrieval from the borehole.
- Manual override capability to release the grapple lifting arms from the waste package in the event of actuator failure.
- Positive lifting arm lock while carrying the waste package to prevent accidental dropping of the load.
- Fail-safe operation

The Cask Grapple, shown in Fig. 5, incorporates the above features. Two lifting arms, made of titanium, pivot at the top end and are normally held in the closed position by compression springs. The lifting arms are opened by pressurizing the stainless steel bellows with air at a pressure of about 275 kPa.

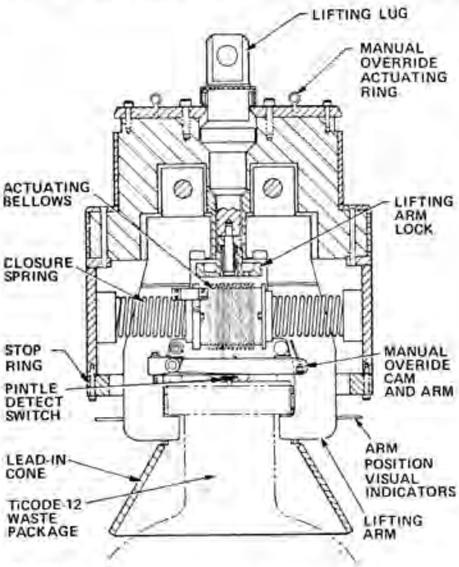

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Fig. 5. Cask Grapple.

When the grapple is raised with the lifting arms closed around the waste package, the lifting arm lock holds the arms tightly in the closed position and prevents dropping of the package. Manual override capability is provided by a system of cams and levers that permits release of the lifting arms by pulling on the actuating rings which are connected by wires to the levers.

Underground Equipment Transporter

The Underground Equipment Transporter transports the different pieces of equipment used in the emplacement and retrieval operations through the access drifts. The larger equipment such as the Shielded Cask Assembly, and the Borehole and Annulus Cutters are transported in the horizontal position and rotated to the vertical position in the emplacement area prior to positioning them on the Floor Shield Valve.

The transporter, shown in Fig. 6, is a steerable, diesel-powered, pneumatic-tired, straddle carrier which is open at one end. It is controlled by an operator either from the cab or by radio remote control.

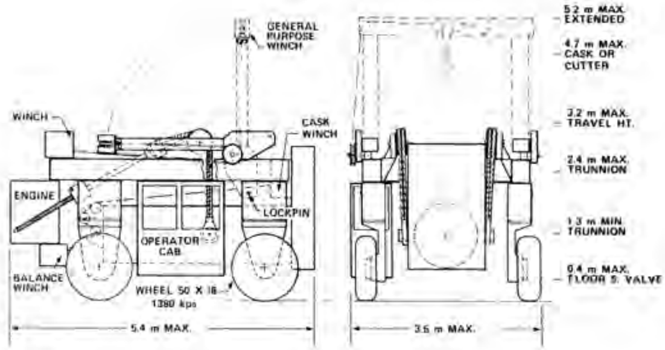

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Fig. 6 Underground Equipment Transporter

The Underground Equipment Transporter is equipped with a 36 tonne capacity main hoist capable of lifting a load located at a height of 1.1 m to a height of 2.4 m. A balance winch is provided for use in conjunction with the main hoist for upending equipment and to hold loads in the horizontal position during transport. In addition, the transporter has a general purpose winch, rated at 9 tonnes, which is used to lower the Annulus Cutter into the borehole. The winch is power-erected when required to be used and is normally in the horizontal position.

The overall dimensions of the Underground Equipment Transporter are shown in Fig. 6. The transporter, with four-wheel steering, is capable of negotiating the most restrictive underground drifts and intersections at WIPP without requiring backing-up of the vehicle.

Floor Shield Valve

The Floor Shield Valve provides shielding at the borehole interface during all emplacement and retrieval operations. It is designed to support and interface with the Shielded Cask Assembly, the Backfill Hopper, the Borehole and Annulus Cutters, and the Shielded Work Enclosure.

The Floor Shield Valve, shown in Fig. 7, is a conventional sliding gate design and consists of a carbon steel housing with the shield gate made of carbon steel and cast lead. The valve overall dimensions are 3 m long, 1.8 m wide, and 0.27 m thick. When open, the valve provides a 1.32 m diameter opening. It weighs 14,000 kg. The Floor Shield Valve gate is opened and closed by an electro-mechanical drive system with provision for a manual override. Removable plugs in the valve housing provide access during off-normal conditions for inspection of the borehole with a Closed Circuit Television (CCTV) camera or for the insertion of hooks for manually opening the Cask Grapple lifting arms.

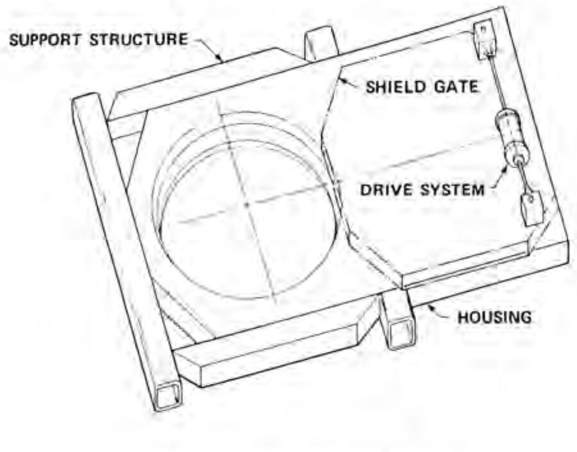

Fig. 7. Floor Shield Valve.

Backfill Hopper

The Backfill Hopper fills the borehole after the emplacement of the waste package with crushed salt or mixtures of bentonite and crushed salt or silica sand having a screened particle size of about 1 cm.

The Backfill Hopper, shown in Fig. 8, is of carbon steel construction, having a cylindrical shape, and provided with a two-stage valve. The hopper is 1.4 m in diameter and has an overall height of 2.2 m. It has to be filled with backfill to a depth of approximately 1.7 m in order to fill the borehole. This depth of backfill provides the necessary shielding when the Floor Shield Valve is opened to discharge the backfill.

The two-stage valve permits slow backfilling though a 15 cm diameter opening. The second stage has a 60 cm diameter opening for faster filling. The valve is actuated using the general purpose winch on the Underground Equipment Transporter.

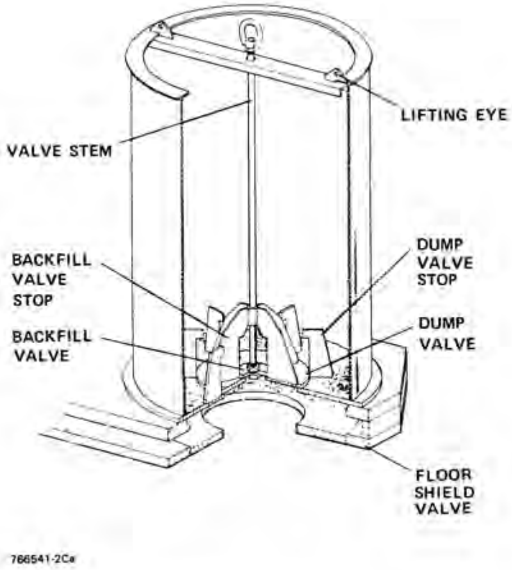

Fig. 8. Backfill Hopper.

Borehole Cutter

The Borehole Cutter cuts a 1.3 m diameter hole to a maximum depth of about 2.5 m. The Vacuum System is used in conjunction with the Borehole Cutter to remove the salt and backfill materials from the hole during cutting operations.

The Borehole Cutter, shown in Fig. 9, has three major components: the inner barrel, the outer barrel, and the support structure. All the structural components are fabricated from carbon steel. The inner barrel has spinning cutters mounted on its bottom plate. The drive system for the cutters is mounted within the inner barrel. The inner barrel rotates and cuts the borehole by telescoping out of the support structure. The outer barrel is keyed to the inner barrel allowing the inner barrel to rotate and telescope. The support structure supports the inner and outer barrels and the rotational and telescoping drive systems.

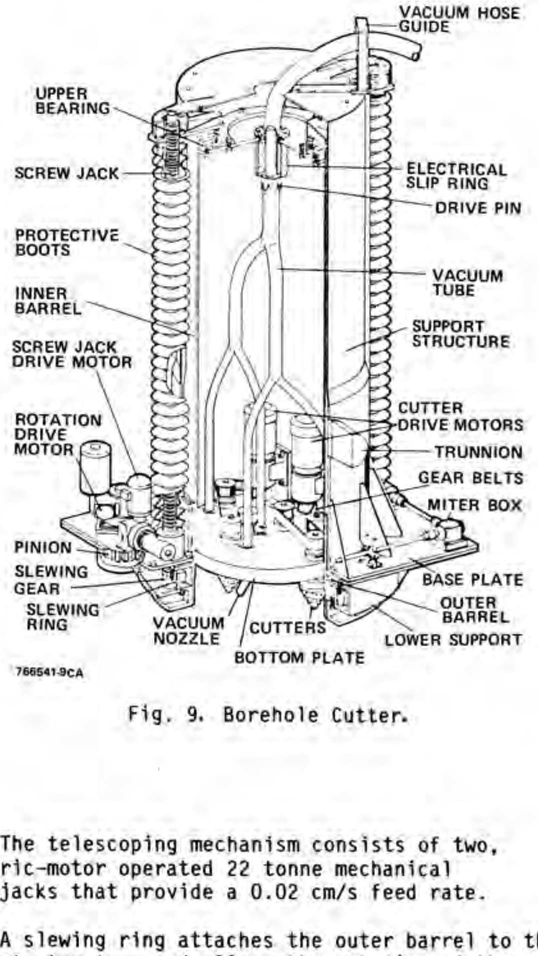

Fig. 9. Borehole Cutter.

The telescoping mechanism consists of two, electric-motor operated 22 tonne mechanical screwjacks that provide a 0.02 cm/s feed rate.

A slewing ring attaches the outer barrel to the support structure and allows the rotation of the outer barrel by means of a gear and pinion drive system. The outer and inner barrels rotate at a speed of 2 rpm.

The cutters are conical with carbide tips brazed to a carbon steel body, as shown in Fig. 10. The Borehole Cutter has four cutters that are positioned at three different radii from the axial centerline of the inner barrel. Two of these cutters are located on the outer radius to minimize wear and tear. Each cutter spins on its axis at 254 rpm and into the salt with a milling action while the inner barrel rotates

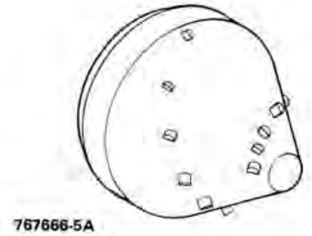

Fig. 10. Cutter Head.

at 2 rpm. The combined rotation and telescoping of the inner barrel moves each cutter in a helical pattern down through the salt. The 21.6 cm diameter of each cutter causes overlapping of the cutting paths to produce a circular borehole as shown in Fig. 11. A 5 cm diameter vacuum tube is positioned near each cutter to suck away the salt and backfill chips. These vacuum tubes are manifolded into a single tube that is attached to the stationary top plate of the inner barrel. The top plate attaches to the inner barrel through a cross roller bearing which allows the plate to remain stationary while the inner barrel rotates. Electrical cabling to the cutter drive exits the top plate of the inner barrel through an electrical slip ring assembly.

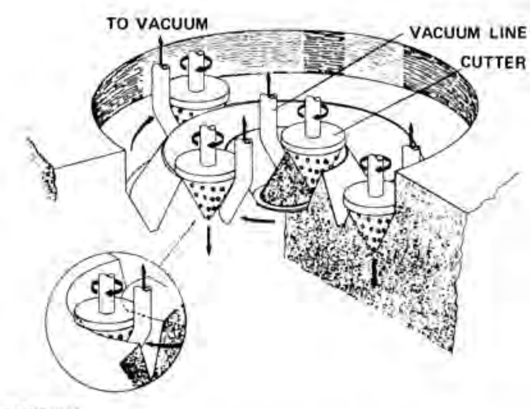

Fig. 11. Borehole Cutting Operation.

The Borehole Cutter is approximately 1.9 m square at the lower end and has an overall height of 4.4 m. It weighs 11,000 kg. Its large size requires that the equipment be transported in the horizontal position through the access drifts, and upended in the emplacement area. Lifting trunnions are provided on the support structure for this purpose.

Annulus Cutter

The Annulus Cutter removes the salt and backfill from around the waste package that could be tilted from the vertical by as much as 10° in any direction, and located at a depth varying from 4.2 to 5.5 m.

An important design consideration was that the DHLW waste packages be retrieved without compromising the surface corrosion data. This required that the Annulus Cutter have provisions for precise alignment with respect to the waste package and for overcoring with minimum contact with the package surface.

The Annulus Cutter, shown in Fig. 12, has three major components: the cutter housing, the drive assembly, and the support base. The outer housing has a telescoping inner frame with cutters that create the annulus. The drive assembly rotates the cutter housing. The support base supports the cutter housing and the drive assembly. All the structural components are fabricated from carbon steel.

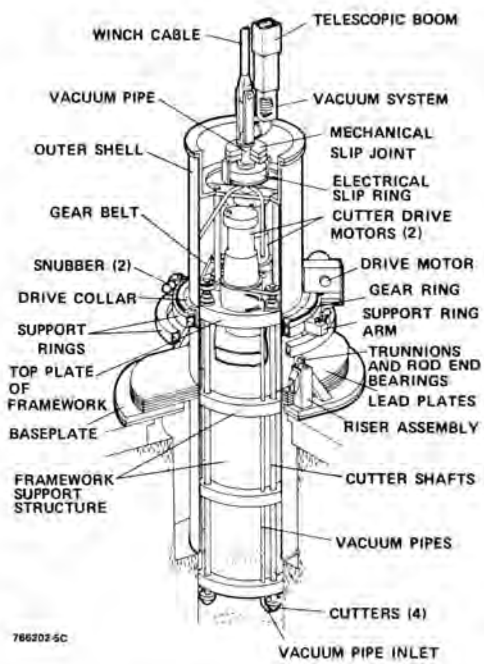

Fig. 12. Annulus Cutter.

The cutter housing has two major components, the inner framework and the outer shell. The inner framework is keyed to the outer shell and both rotate at 2 rpm. Two 4.5 tonne screw jacks telescope the inner framework through the outer shell at a speed of 0.2 cm/s over a maximum travel of 2.85 m.

The inner framework supports four cutter drive shafts spaced 90° apart. Each conical cutter has a maximum diameter of 15 cm and rotates at 400 rpm. The cutter design and cutting action are similar to that for the Borehole Cutter. The salt and backfill chips are removed by 5 cm diameter vacuum tubes that are manifolded into a single tube that exits the cutter through a mechanical slip joint.

The drive assembly supports and rotates the cutter housing and allows lateral repositioning of the cutter housing for precise alignment with respect to the waste package. It consists of a drive collar, a ring gear, a drive collar support ring, and a gear motor. The ring gear is designed to be clamped to the housing after the cutter housing is lowered to the full depth of the borehole that is cut earlier with the Borehole Cutter. The general purpose winch on the Underground Equipment Transporter is used to raise and lower the cutter housing.

The support base mounts on the Floor Shield Valve and supports the Annulus Cutter. The support base:

- Aligns the Annulus Cutter with respect to the waste package.
- Provides flexibility for adjustment to compensate for the ±2° and ±5 cm uncertainty in the location of the waste package.
- Reacts the torque applied by the rotational drive motor.
- Provides radiation shielding regardless of Annulus Cutter tilt or position.

The support base incorporates a system of trunnions and rod-end bearings secured to a support ring that in turn supports the ring gear. This feature allows the Annulus Cutter to be tilted at an angle. A waste package that is tilted up to 10° is accommodated by orienting the support base to the proper direction and tilting the cutter housing and drive assembly on the trunnion axis to the proper angle.

The Annulus Cutter is the tallest component used in the retrieval system, with an overall height of 4.65 m. It weighs 8000 kg.

Vacuum System

The Vacuum System evacuates the salt and backfill chips generated during cutting operations with the Borehole and Annulus Cutters and the Shielded Work Enclosure. These retrieval equipment are designed to be compatible with a trailer-mounted vacuum system provided with High Efficiency Particulate Air (HEPA) filters. The vacuum system has a capacity of about $0.5 m^3/s$, and 500 mbar suction at the equipment interface.

The use of the Vacuum System effectively confines any contamination resulting from an inadvertent breach of the waste package to within the borehole and the Vacuum System. The Vacuum System is provided with radiation detectors to sense any contamination entering the system.

Shielded Work Enclosure

The primary functions of the Shielded Work Enclosure are to:

- Provide shielded access to the top of the waste package after the Borehole Cutter has cut a borehole close to the top of the waste package pintle.
- Remove the salt and backfill from around the pintle and head of the waste package for precise location and alignment of the Annulus Cutter.

The Shielded Work Enclosure, shown in Fig. 13, is a heavy-walled, cylindrical carbon steel structure. It weighs 9,000 kg. The top portion consists of a system of three rotating plugs. The smallest of three plugs incorporates a telescopic boom to which the salt removal tooling is attached. Other features include the provision of a vacuum line for removal of chips, lead glass windows, a floodlight, and a CCTV system for visual observation of the pintle during salt removal operations.

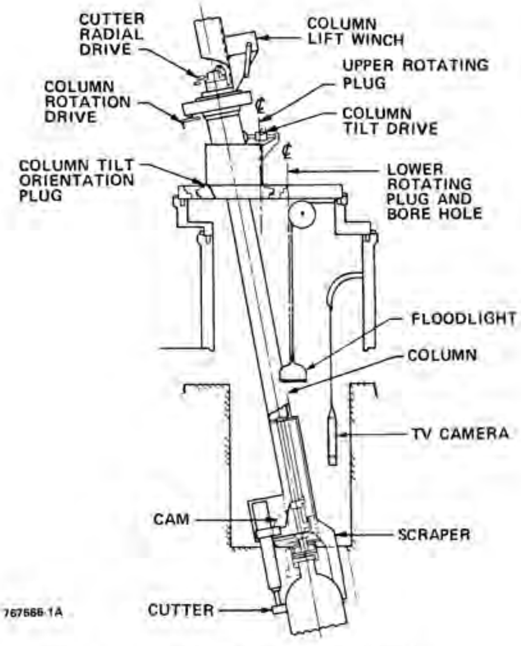

Fig. 13. Shielded Work Enclosure.

The rotating plug arrangement permits precise positioning and angular alignment of the salt cutting tools. An orbital type cylindrical cutter with tungsten carbide tips is mounted at the end of the telescopic boom to remove the salt from around the pintle and the hemispherical head of the waste package.

OPERATING SEQUENCE

The operating sequence for the emplacement and the retrieval of a waste package is shown in Table II. A typical emplacement operation is estimated to take about 5 hours , while a typical retrieval operation can be performed in about 20 hours.

DEVELOPMENT TESTING RESULTS

Testing on a very limited scale was performed to determine:

- Cutter power requirements and cutting speeds.
- Axial loading requirements for the cutter.
- Size of salt chips
- Rate of salt removal

The tests were conducted on a 0.9 m diameter salt block obtained from WIPP and using a 12.7 cm diameter cutter. The test results are given in Table III.

Additional tests were performed using the same cutter in conjunction with a vacuum system to determine the ability of the vacuum line to evacuate wet backfill and salt. A 5 cm vacuum tube was positioned close to the cutter for this test. The full-depth groove in the salt block created during the preceding tests was filled with salt and backfill having various moisture contents and the cutter run through the groove. The results, given in Table IV, show that the cutting system will effectively handle wet backfill and salt during retrieval.

TABLE II

Emplacement and Retrieval Operations

Emplacement	Retrieval
• Install Floor Shield Valve (FSV) Over Borehole	• Install FSV Over Waste Package Location
• Transport Shielded Cask Assembly (SCA) and Install on FSV	• Transport and Install Borehole Cutter on FSV
• Transfer Waste Package into Borehole	• Cut Borehole to Near Top of Waste Package
• Remove SCA and Install Backfill Hopper	• Remove Borehole Cutter and Install Shielded Work Enclosure (SWE)
• Backfill Borehole and Remove FSV	• Cut Salt/Backfill to Expose Waste Package Pintle and Head
	• Remove SWE and Install/Align Annulus Cutter
	• Overcore the Salt/Backfill from Around Full Length of Waste Package
	• Remove Annulus Cutter and Install SCA
	• Transfer Waste Package into SCA and Transport

TABLE III

Cutter Test Results

Cutter RPM Selected (13 cm Head)	400
Cutting Speed	10 cm/sec
Cutter Horsepower (240 RPM, 10 cm Deep Cut)	$\leq$ 0.75 kW
Load Required on Cutter Head	~ 90 kg

Size of Salt Chips

~75%	0.25 to 8 mm Size
<0.2%	< 0.08 mm (Very Little Dust)

Rate of Salt Removal

~ 17 kg/Min.

At This Rate, The Annulus Around Waste Package Could be Cut in ~40 Minutes.

TABLE IV

Salt and Backfill Removal Test Results

- Need a 5cm Pipe Size for Vacuum Tube at Cutter Head
- Vacuum System Used – Flow Velocity of 27 - 34m/sec FPS
  235 to 340 mbar
- Wet Backfill Removal Capability

70% Bentonite 30% Sand	<22% Saturated Brine
60% Bentonite/Sand Used Above 30% Salt	<18% Saturated Brine
100 Wt % Salt (All % By Weight)	$\leq$ 14% Saturated Brine

- Dry Salt Removal Tests

At Least 3.0m of Vertical Pipe Filled with Salt Chips Can Be Cleared by Vacuum System.

CONCLUSIONS

This paper has described the design considerations relating to the retrievability of waste packages emplaced in vertical boreholes in a repository in salt. The impact of those considerations on the design of the first-of-a-kind emplacement and retrieval equipment that was developed in support of the Sandia DHLW experiments at WIPP, and a description of that equipment, are also presented. The equipment for performing emplacement and retrieval operations in a commercial repository in salt could be different, involving a higher degree of automation and being less operator-intensive. However, the WIPP design experience has provided valuable insight into the repository requirements and interfaces unique to the salt medium, and offers a design base upon which future repository equipment may be developed.

An important lesson learned from the WIPP experience is the importance of establishing realistic emplacement and retrieval equipment operating envelopes prior to finalizing critical facility design parameters such as access drift and emplacement room layouts and dimensions. Otherwise, the penalties are severe in terms of unnecessary equipment complexity and increased capital equipment and operating costs.

It is noted that the testing program was only intended to provide the minimum data to allow the designers to proceed with the detailed design of the salt cutting equipment with a reasonable amount of confidence. The equipment designs had the flexibility for varying the critical operating parameters such as cutting speeds and feeds based on the results of full-scale prototype testing at WIPP.

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