# Waste Handling and Emplacement Options for Disposal of Radioactive Waste in Deep Boreholes

**16277**

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## ABSTRACT

Traditional methods cannot be used to handle and emplace radioactive wastes in boreholes up to 16,400 feet (5 km) deep for disposal. This paper describes three systems that can be used for handling and emplacing waste packages in deep borehole: 1) a 2011 reference design that is based on a previous study by Woodward–Clyde in 1983 in which waste packages are assembled into "strings" and lowered using drill pipe; 2) an updated version of the 2011 reference design; and 3) a new concept in which individual waste packages would be lowered to depth using a wireline. Emplacement on coiled tubing was also considered, but not developed in detail. The systems described here are currently designed for U.S. Department of Energy-owned high-level waste (HLW) including the Cesium-137/Strontium-90 capsules from the Hanford Facility and bulk granular HLW from fuel processing in Idaho.

For deep borehole disposal, the waste packages will need to be narrower and more robust than those waste packages used for near-surface disposal. The reference waste package will have a maximum outer diameter 11 inches (28 cm) and be approximately 18.5 feet (5.7 m) long. With an anticipated in-situ hydrostatic pressure of approximately 10,000 pounds per square inch the reference waste package will be made of steel with a one-inch wall thickness. Despite the thick steel wall, the unshielded contact dose rate could be as high as several hundred rem per hour. Traditional methods cannot be used to manage such long, narrow, heavy and radiologically hot packages.

For all three systems, waste handling operations are conceptualized to begin with the onsite receipt of a purpose-built Type B shipping cask that contains a waste package. This purpose-built shipping cask has a unique feature, in that it can be opened from either end. Emplacement operations begin when the cask is upended over the borehole, locked to a receiving flange or collar. The scope of emplacement includes activities to lower waste packages to total depth, and to retrieve them back to the surface when necessary for any reason.

In the 2011 reference design and the updated version of this design, the waste packages are lowered to the emplacement depth through a guidance liner. Using automated equipment in a shielded basement over the borehole, individual waste packages will be assembled (screwed together) into a string of up to 40 packages

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with a total length of ~ 700 feet (215 m). Drill pipe will then be used to lower the string to the emplacement interval – a process that could take 32 hours. The paper describes the equipment and the steps necessary to handle and emplace waste packages using drill pipe.

This paper also presents a new concept in which individual waste packages would be lowered to depth using a wireline. The paper describes the equipment and the steps necessary to handle and emplace waste packages using wireline; conceptually a faster, less expensive and possible safer method of waste emplacement.

The deep borehole disposal (DBD) concept calls for siting a borehole (or array of boreholes) that penetrate crystalline basement rock to a depth below surface of about 16,400 ft (5 km). Waste packages would be emplaced in the lower 6,560 ft (2 km) of the borehole, with sealing of appropriate portions of the upper 9,840 ft (3 km). A deep borehole field test (DBFT) is planned to test and refine the DBD concept. The DBFT is a scientific and engineering experiment, conducted at full-scale, in-situ, without radioactive waste.

## INTRODUCTION

For over 50 years deep borehole disposal (DBD) has been considered for disposal of radioactive waste (Hess et al. 1957); but the concept has never been tested. A 2014 U.S. Department of Energy (DOE) report "… recommends that DOE retain the flexibility to consider options for disposal of smaller DOE-managed waste forms *in deep boreholes …*" (emphasis added, DOE, 2014) and a deep borehole field test (DBFT) is now planned to test and refine the DBD concept.

A reference design for a DBD system and a DBFT are provided in Arnold et al. (2011) and summarized below. For the anticipated operations, the reference design is to drill to 5 km (16,400 ft) with a 0.43 m (17 inch) diameter at total depth (TD). For waste emplacement operations, a guidance casing with a 0.317 m (12.46 inch) internal diameter will extend from the surface to TD.

With its narrow profile and very high down-hole pressures[2] traditional waste packages and methods cannot be used to handle and emplace radioactive wastes. The overall purpose of this work is to develop the conceptual design of a system to handle and emplace waste packages in deep boreholes; so that the deep borehole field test can simulate (to the extent practicable) the anticipated actual handling and emplacement system.

Three systems for handling and emplacing waste packages in deep borehole are reviewed: 1) a 2011 reference design that is based on a previous study by Woodward–Clyde in 1983 in which waste packages are assembled into "strings" and lowered using drill pipe; 2) an updated version of the 2011 reference design; and

[2] The design basis downhole pressure is 65 MPa (9,560 psi) based on assumed fluid density of 1.3 times the density of water in a 5-km column.

3) a new concept in which individual waste packages would be lowered to depth using a wireline. Emplacement on coiled tubing was also considered, but not developed in detail. The conceptual designs of the two modes of emplacement (updated drill pipe and wireline) were used in a design selection study that compared the costs and risks associated with two handling and emplacement methods.

The most important requirements for the DBFT and DBD operations are to ensure worker health and safety, and to preserve environmental quality.

The systems described here are designed for DOE-owned granular High-Level radioactive Waste (HLW) materials, vitrified HLW, HLW in sealed capsules (i.e., the Cesium-137/Strontium-90 (Cs/Sr) capsules from the Hanford Facility) and spent fuel.

## DEEP BOREHOLE DISPOSAL CONCEPT

The DBD concept calls for siting a borehole (or an array of boreholes) that penetrates crystalline basement rock to a depth below surface of about 5 km (16,400 ft). Waste packages would be emplaced in the lower 2 km (6,560 ft) of the borehole, with sealing of appropriate portions of the upper 3 km (9,840 ft) (see Figure 1).

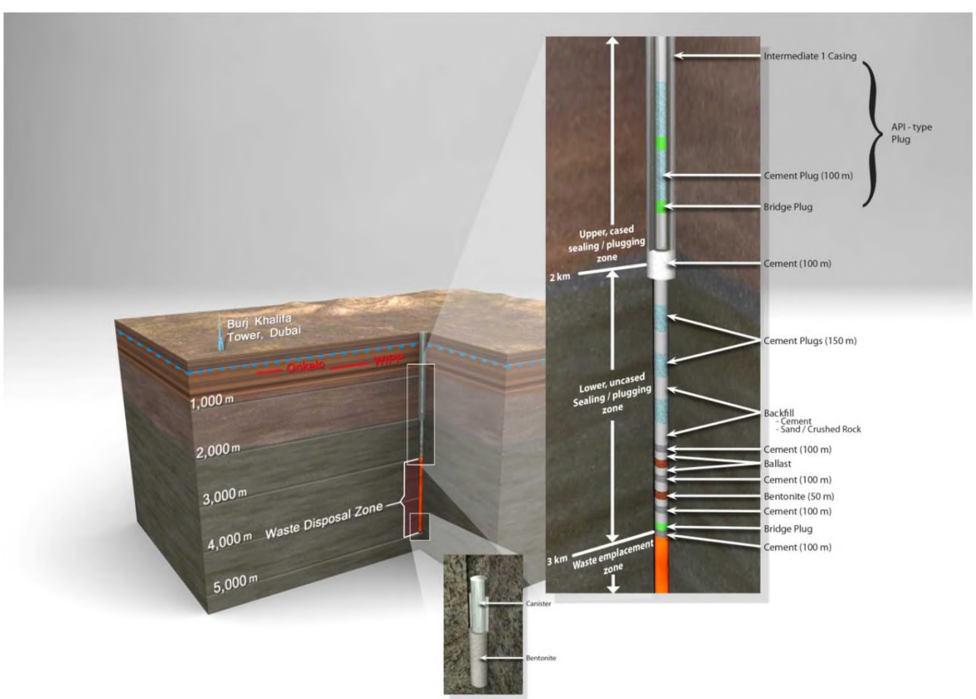


**Figure 1. Conceptual design of DBD of radioactive waste. The dashed blue line indicates typical lower extent of useable fresh groundwater resources (from Hardin, 2015)**

Several factors suggest that the DBD concept is viable and safe. Crystalline basement rocks are relatively common at depths of 2 to 5 km in stable continental regions, suggesting that numerous geologically appropriate sites exist. Existing drilling technology permits the reliable construction of sufficiently large (0.43 m) diameter boreholes to a depth of 5 km at an estimated cost of about $27 M USD each (Arnold et al. 2011, for subsequent holes, for drilling and completion only).

Low permeability and high salinity in the deep crystalline basement at many continental locations suggest very limited interaction with shallower sources of useable groundwater which is the most likely pathway for human exposure. Groundwater density stratification due to salinity would oppose upward thermal convection from heat-generating waste. Geochemically reducing conditions in the deep subsurface limit the solubility and enhance sorption of many radionuclides, leading to very limited mobility in groundwater.

## DEEP BOREHOLE FIELD TEST

A DBFT is planned to test and refine the DBD concept. The foremost objective of the DBFT is to confirm the safety and feasibility of the DBD concept for long-term isolation of radioactive waste. The DBFT is a scientific and engineering experiment, conducted at full-scale, in-situ, without radioactive waste (see Figure 2). The DBFT has the following objectives:

- Evaluation and verification of geological, geochemical, geomechanical, and geohydrological conditions at a representative location;
- Demonstration of drilling technology and borehole construction to 5 km depth in crystalline basement with sufficient diameter for cost-effective waste disposal;
- Demonstration of the ability to handle, emplace and retrieve prototype waste packages; and
- Demonstration of pre-closure and post-closure safety.

Data from the DBFT will provide an opportunity to validate and improve waste package design, and the design of the handling and emplacement systems. For a meaningful field test, the test system should closely simulate anticipated actual DBD operations. Towards this end, a number of studies have been undertaken to anticipate actual disposal operations. These studies have determined that two methods might be used to lower waste packages into a disposal borehole; lowering a string of waste packages using drill pipe and lowering single waste packages using a wireline.

## WASTE HANDLING AND EMPLACEMENT

The scope of waste handling is defined to begin with the onsite receipt of a purpose-built Type B shipping cask that contains a waste package. Waste handling operations end when the shipping cask is upended over the borehole, locked to a receiving flange or collar. The scope of emplacement includes the activities to lower

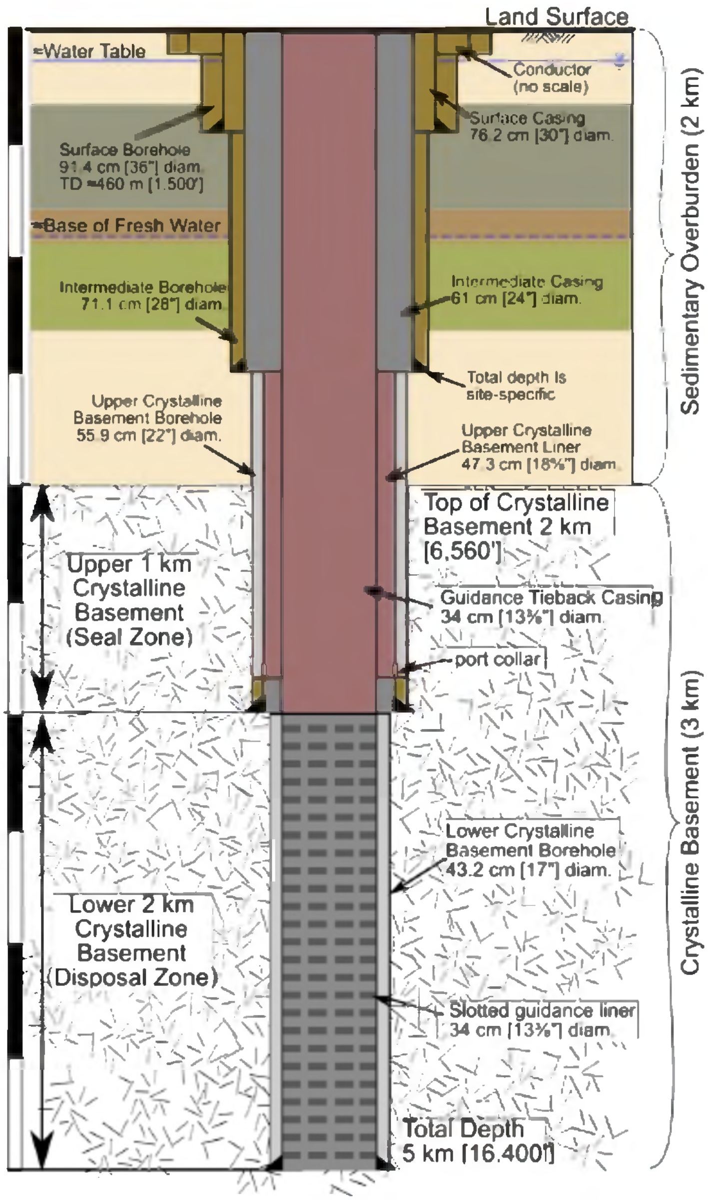


**Figure 2 DBFT Conceptual Design (Kuhlman, K.L., et al, 2015)**

the waste packages from the shipping cask to TD, and to bring waste packages back to the surface when necessary for any reason as part of emplacement operations.

## WASTE PACKAGES

The waste packages are the items that will be handled and emplaced. The conceptual design of the waste packages is influenced by: the characteristics of the borehole, the downhole environment, the characteristics of the waste to go in the waste packages and the characteristics of the handling and emplacement system.

As shown in Figure 2, the borehole will have a ~34-cm (13-3/8-inch) outside diameter (OD) "guidance" casing from the surface to TD for smooth emplacement and removal operations. This guidance casing has a ~31.7-cm (12.46-inch) inside diameter (ID). For the conceptual design, a radial clearance of 1.9 cm (0.75 inch) was selected, and the maximum OD of the waste package is therefore 27.9 cm (11 inches).

For handling and emplacement, the exterior of the waste package surface, including connections, must be free of exposed steps or ridges that could hang up on casing joints, hangers, etc., when moving upward or downward. All packages will have a detent or collar at the lower end that engages with the "elevator" ram to support the package string during assembly as discussed below. All packaged with have threaded ends for interface with other packages and/or interface with the emplacement equipment. The threads will be standard drill pipe threads.

To accommodate various waste forms, the internal dimension of the waste package will be 5 m (16.4 ft). The 5 m overall length is a maximum internal length, and the package length can be adjusted by varying the length of the tubular part. For radiological safety, the upper 30.5 cm (1 ft) of the waste package will be solid steel (i.e., a 30.5-cm thick shielding plug), and the lower endcap thickened for strength.

Waste forms such as the Cs/Sr capsules are radiologically hot and the unshielded contact dose rate at the outside of the waste package could be as high as several hundred rem per hour. Waste packages may also be thermally hot, for example a package of Cs/Sr capsules could radiate 100 to 500 W per meter of length, depending on the waste age and the mode of packaging.

At TD the in situ temperature could be as high as 170°C (338° F). For heat-generating waste the peak package surface temperature could be 250°C (480°F), representing 80 C° rise. This latter temperature is based on thermal analysis from Arnold et al. (2014) for packages containing Cs/Sr capsules stacked end-to-end, with relatively high heat output, emplaced in 2020.

For design purposes it is assumed that borehole pressure will be less than or equal to that produced by a uniform fluid column with 1.3 times the density of pure water, at up to 5 km depth. The resulting design basis hydrostatic pressure at the bottom of the hole is 65 MPa.

Traditional waste packages methods cannot be used to contain radioactive wastes in boreholes up to 5 km deep and based on the characteristics listed above and other inputs, Su and Hardin (2015) developed four conceptual waste packaging designs for DBD. Two of the four designs have a 27.3-cm (10.75-inch) OD for the DBD system described above, and two of the four designs have a 12.7-cm (5-inch) OD for use in a 17.8–cm (7-inch) OD guidance casing. For each OD, there is a flask-type design with a threaded plug for loading granular HLW or small diameter Cs/Sr capsules, and there is a flush-type design for receiving canistered wastes.

Canistered wastes are wastes previously loaded in thin-walled canisters or liners. Canistered wastes can be slid into the internally flush-type waste package prior to welding the end-cap on. Figures 3 and 4 show one of the four conceptual designs; in this case the 27.3-cm OD flask-type design.

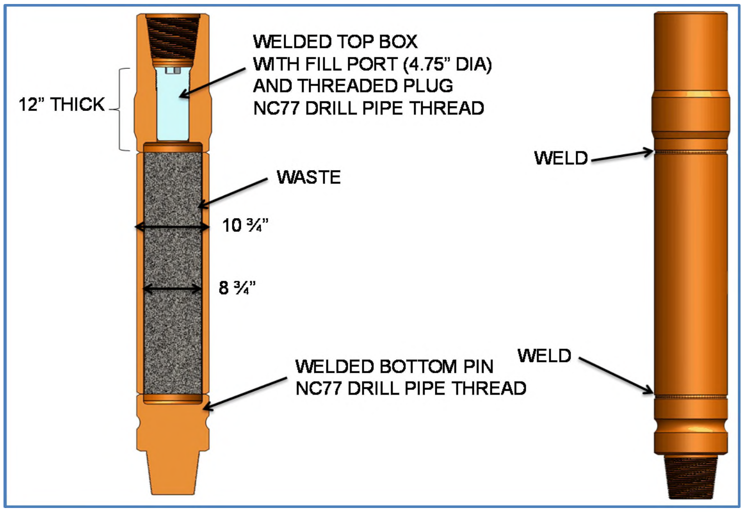


**Figure 3. 27.3-cm (10.75-inch) OD flask-type design, aspect ratio shortened for illustration (Su and Hardin 2015)**

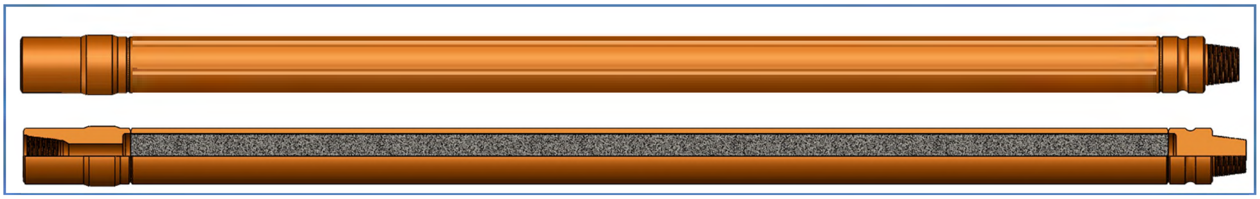

**Figure 4. 27.3-inch OD flask-type design, shown at true aspect ratio (Su and Hardin 2015)**

It is estimated that the loaded waste packages will have a dry loaded maximum weight of 2100 kg (4,620 lb) and a buoyant loaded maximum weight of 1,650 kg (3,630 lb) in drilling mud 1.3 times the density of pure water.

In summary, the waste packages will be heavy, radiologically-hot, thermally-hot, long and narrow (5.6 m by 0.27 m).

## RECEIPT OF THE SHIPPING CASK

Each waste package would arrive at the site in a purpose-built Type B shipping cask, on a purpose-built trailer. Only one waste package can be carried in a shipping cask. Based on operational experience at the Waste Control Specialists (WCS) facility near Andrews, Texas, only one shipping cask and one package containing highly radioactive waste can be handled per day. At the WCS site it takes 4 days to complete an emplacement cycle, but one shipping cask can be unloaded and released for reuse every 24 hours (Britten 2013).

The purpose-built Type B shipping cask will be a hollow, right circular cylinder with doors on each end that can be operated remotely. The inner diameter of the shipping cask will be a clearance fit with the waste package, which will limit gamma shine when the upper door is open. The cask will also have permanently fixed range-limiting pins at the top that prevent inadvertent lifting of the waste package out of the cask. Lifting a package out of the cask could expose all rig workers to strong gamma radiation.

When each shipping cask arrives at the DBD facility it will be radiologically surveyed. After check-in activities, the impact limiters will be removed from the ends. A crane and associated equipment will be required. After removal of the impact limiters, the tractor-trailer with the shipping cask will be directed to the disposal borehole. This receipt procedure, and the shipping cask configuration, would be same for both drill-string and wireline emplacement.

## WASTE HANDLING AND EMPLACEMENT OPTIONS

The conceptual design of the two modes of handling and emplacement of waste packages were developed.  In the drill pipe design, waste packages are assembled in the top of the borehole into a string of 40 waste packages, which are then lowered to the emplacement interval using 27.4 m (90 ft) stands of drill pipe. The 2011 drill pipe reference design is reviewed briefly, followed by the development of the updated drill pipe design.

In the wireline design, waste packages are lowered individually using a wireline. Because of waste packages maybe radiologically hot, all emplacement activities (drill pipe and wireline) must be done remotely.

Critical design criteria are that the waste packages not be dropped or become stuck during emplacement or retrieval. For both options, the holding mechanisms will be redundant so that single-point electrical, hydraulic or mechanical failures cannot cause release of a package or string, resulting in: 1) one or more waste packages dropped in the borehole, potentially onto other packages; or 2) a drill string dropped onto packages connected to its lower end, or onto packages already emplaced.

## 2011 DRILL PIPE REFERENCE DESIGN

The 2011 reference design for waste handling and emplacement (Arnold et al. 2011) is based loosely on a previous study (Woodward–Clyde 1983) which itself is based on the Spent Fuel Test-Climax (SFT-C) at the Nevada National Security Site (formerly the Nevada Test Site), conducted from 1978 to 1983. The SFT-C was an operational demonstration in which 11 canisters, each containing one irradiated fuel assembly, were transferred through a 416 m (1,365 ft) deep borehole into the

Climax Mine. The spent fuel was stored underground for three years, and then retrieved through the same borehole (Patrick 1986).

In the 2011 presentation of this design, the waste packages are assembled within the top of the borehole into a string of 40 waste packages and lowered to the emplacement depth using drill pipe. Approximately 400 waste packages are placed in each borehole (e.g., 10 strings of 40 packages each). The handling and emplacement steps are detailed in Arnold (2011), summarized in Cochran and Hardin (2015) and not repeated here.

## UPDATED DRILL-STRING HANDLING AND EMPLACEMENT OF STRINGS OF WASTE PACKAGES

### Handling and Emplacement Components

After drilling and construction of the disposal borehole is complete, and the drilling rig is moved off, a number of modifications will be made to create the integrated facilities needed to emplace waste packages. Modifications will be made in several phases: basement construction, surface pad installation, transfer carrier installation, emplacement workover rig setup, and installation of the control room and ancillary surface equipment. The following paragraphs describe modifications for a reference-size borehole (0.43-m (17-inch) diameter in the disposal zone), but similar facilities would be used for disposal boreholes of different sizes.

Basement construction – Waste packages will be assembled into a string of 40 in a "basement" built over the borehole with the top of the basement being at-grade. The basement will serve two main functions: 1) provide a shielded facility to house the BOP and other control equipment for handling waste packages, and 2) reduce the height requirement for the shipping cask, emplacement rig, and related equipment. The basement structure will need to withstand loading at the ground surface by the emplacement rig.

Figure 5 shows a cutaway of the basement, which could be up to 9 m (30 ft) deep. The basement contains power tongs for rotating the waste packages and redundant equipment for holding up to 40 waste packages: the power slips and the "elevator" ram fitted to the indent in the waste packages. The basement will also house the blow-out preventer (BOP), if needed, and equipment to handle the drilling mud.

Surface pad installation – A surface pad will be constructed from reinforced concrete to transmit support loads to the emplacement workover rig, and to anchor the transfer carrier track and align it over the borehole.

Transfer carrier installation – Following the Woodward-Clyde (1983) concept, a track-mounted transfer carrier will deliver the shipping cask over the last 13 m (50-ft) distance to the borehole. The remotely-operated transfer carrier will grip the steel track both above and below so that they cannot be derailed.

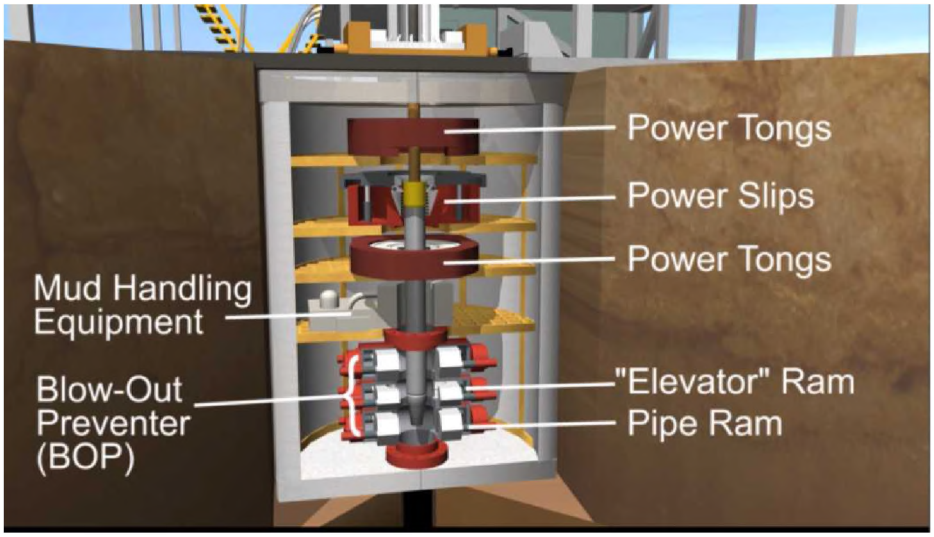


**Figure 5. Shielded "basement" equipment for handling waste packages.**

Emplacement workover rig setup – The emplacement rig will used to assemble waste packages into strings, lower the strings to the emplacement depth, set bridge plugs and cement plugs, remove casing, and seal the borehole. The emplacement rig floor will sit well above ground level, standing on a steel-frame substructure. The emplacement rig will be similar to a drill rig but lighter and less costly. It will have the capacity to emplace 40 waste packages with approximately 4,770 m (15,660 ft) of drill pipe. The combined weight of waste packages and drill pipe will be approximately 21,300 kg (468,000 lb) based on the buoyant weight of 40 waste packages in pure water and 4,770 m of drill pipe. Though this is not the heaviest lift; which will be the removal of the guidance liner tieback assuming 3,000 m (10,000 ft) of the ~34-cm (13-3/8 inch) OD guidance casing.

Control room - Waste handling operations will be controlled from a dedicated control room located on the rig floor, near the driller.

Ancillary equipment - Ancillary equipment associated with the emplacement rig will include generators, pipe handling, hydraulic pumps, cement and mud handling equipment, waste handling equipment laydown, a warehouse, a shelter and comfort facilities.

## Handling Steps

Before the shipping cask is placed over the borehole, a caliper log will be run to ensure safe condition of the borehole. A crane will lift the Type B shipping cask by one end from the trailer and lower it onto the transfer carrier. The transfer carrier will move down the track and position itself over the borehole receiving collar. Kneeling jacks at each wheel of the transfer carrier can lower the cask down onto the receiving collar where it is clamped or bolted in place over the basement and borehole.

## Emplacement Steps

After the shipping cask has been bolted/secured to the receiving collar, the following steps will be used to make up a string of waste packages in the borehole and then use drill pipe to lower the string of packages to the emplacement interval in the borehole. The number of packages in a string is TBD based on logistical and safety analyses.

1. Remotely open the upper door on the shipping cask (shielding is provided by the shield plug integral to the waste package).
2. Attach the breakaway sub to the rig hoist.
3. Verify radial restraining bolts on lower end of shipping cask (restrain waste package from spinning when threading on drill string).
4. Remotely attach the breakaway sub to the threaded connection on the upper end of the waste package inside the Type B shipping cask (without shearing the rotation restraining bolts).
5. Back out the rotation restraint bolts from lower end of shipping cask.
6. Slightly lift the waste package to take weight of lower door.
7. Check status of breakaway sub, cask doors, etc. (these are interlocked).
8. Remotely open the lower door on the shipping cask.
9. If this is the first package (the instrumentation package), then remotely lower the package to correct position, grip it with both the power slips and the "elevator" ram, engage the basement tong, and apply weight to set the slips.
10. Remotely open blind ram and drill pipe ram.
11. If this is a subsequent waste package in a string, remotely lower the package onto the previous package in the slips.
12. Rotate the breakaway sub/waste package using the automated tender at the rig floor, and make the threaded connection with the previous package.
13. Verify threaded connection between packages (e.g., log makeup torque).
14. Disengage basement tong and "elevator" ram.
15. Slightly lift the package string to disengage the emplacement power slips.
16. Lower the string so it is in correct position, grip it with both the power slips and the "elevator" ram, engage the basement tong, and apply weight to set the slips.
17. Disconnect the breakaway sub and raise it back through the shipping cask.
18. Close door on t op of basement and doors on the shipping cask.
19. Reverse handling steps to remove shipping cask.
20. Repeat handling steps and steps 1 through 18, to add additional waste packages to the string.
21. After final waste package is added, reverse the steps to remove shipping cask.
22. Remove the breakaway sub and attach the J-slot device to the first stand of drill pipe.
23. Thread the J-slot device into the top waste package. Torque the connection.
24. Verify threaded connections between drill string and package string.
25. Disengage basement tong and "elevator" ram.
26. Slightly lift the package string to disengage the emplacement power slips.
27. Lower string into position for adding a stand of drill pipe.

28. Actuate the drill pipe slips (on the rig floor) and basement pipe ram (and/or emplacement power slips).
29. Add another stand of drill pipe; make the joint with the "iron roughneck."
30. Disengage the basement pipe ram.
31. Slightly lift the string and disengage the drill pipe slips (and emplacement power slips if used).
32. Lower string into position for adding another stand of drill pipe, or lower string into emplacement position (if on bottom).
33. Repeat steps 28 to 32 until emplacement depth is achieved.
34. With the string secured in drill pipe slips, attach a rotation device (e.g., kelly).
35. Disengage the basement pipe ram.
36. Slightly lift the string and disengage the drill pipe slips (and emplacement power slips if used).
37. Gradually lower the string until the force on the bottom is within specification to operate the J-slot safety joint.
38. Disengage the canister string using the J-slot safety joint.
39. Hoist the string into position for removing the rotation device.
40. Actuate the drill pipe slips, basement pipe ram, and emplacement power slips if used.
41. With the string in the slips, remove the rotation device.
42. Disengage the basement pipe ram.
43. Slightly lift the string and disengage the drill pipe slips (and emplacement power slips if used).
44. Hoist the string into position for removing another stand of pipe.
45. Actuate the drill pipe slips, basement pipe ram, and emplacement power slips
46. Remove another stand of drill pipe, breaking the joint with the "iron roughneck."
47. Repeat steps 42 to 46 to trip out of hole.
48. Remotely close the blind ram.

## WIRELINE HANDLING AND EMPLACEMENT OF SINGLE WASTE PACKAGES

### Handling and Emplacement Components

After the drill rig is moved off of the borehole and before wireline emplacement can begin, a number of modifications will be performed. Construction is divided into several sub-systems: surface pad, BOP shield, hoist and wireline, cable head, headworks for wireline sheave, ancillary surface equipment, completion/sealing workover rig and a control room (see Figure 6). After waste emplacement, a completion/sealing workover rig will be used for final sealing and plugging.

Surface pad – A steel-reinforced concrete pad, approximately 25 feet on a side, will be poured around the wellhead at grade level, as a base for the BOP shield and other items.

**Figure 6 wireline handling and emplacement components.**

BOP shield – A robust radiation shield will be constructed around the BOP (Figure 6). A heavy, cylindrical steel receiving collar will fit into the hole and bolt to a flange on a section of the casing that is attached to the wellhead stack. Mud control piping will run from the wellhead through the BOP shield, to a surge tank and pump located outside.

Hoist and wireline – A standard truck- or skid-mounted wireline with 6100 m (20,000 ft) of 1.2 cm (0.488-inch) double-armored 7-conductor electric wireline can be used for emplacing waste packages. Note that the emplacement concept described here could, in principle use coiled steel tubing for waste package emplacement instead of an electric wireline. Coiled tubing could be considered for waste package emplacement, in variants of the drill-string method (which includes a basement), or the wireline method (for single packages). Coiled tubing fatigue and safety were key considerations for focusing on drill-pipe and wireline.

Cable head – An electrically actuated cable head will release packages in the emplacement position.

Headworks for wireline sheave - Alignment and support of the wireline sheave over the borehole will be provided by a steel-frame headworks.

Ancillary surface equipment – During waste emplacement, cement plugs in the disposal zone will be set using a coiled tubing truck, with separate mud handling and cement handling systems. Bridge plugs (to locate the cement) can be set using either the coiled tubing or the wireline. Other equipment associated with the completion/sealing rig will be organized on the surface, including generators, cement and mud handling equipment, a warehouse, a shelter and comfort facilities.

Completion/sealing workover rig – A workover rig will be used to remove the guidance liner tieback (approximately 550,000 lb as discussed previously) and the intermediate casing section from the seal zone. The same rig will be used for seals emplacement and plugging of the disposal borehole.

Control room – Waste handling operations will be managed from a control room that is with the hoist.

All systems will be tested after fabrication, and on-site with empty (“dummy”) waste packages prior to operations. Standard operating procedures (SOPs), maintenance procedures, and contingency procedures will be developed.

### Handling Steps

Before the shipping cask is placed over the borehole, a caliper log will be run to the next waste emplacement position, to ensure safe condition of the borehole.
A crane will be used to lift the shipping cask by one end from the trailer and place it in vertical orientation in the receiving collar. The shipping cask will be secured / bolted to the receiving collar in preparation for emplacement.

### Emplacement Steps

After the shipping cask has been bolted/secured to the receiving collar, the following steps will be used to lower individual waste packages to the emplacement interval by wireline:

1. Remotely open the upper door on the shipping cask (shielding is provided by the shield plug integral to the waste package).
2. Manually set restraints on upper door to prevent inadvertent closing on wireline.
3. Attach the cable head to the upper end of the waste package, either remotely or accessing the top of the waste package using a portable worker platform.
4. Slightly lift the waste package with the wireline to take load off lower door (permanently fixed, range-limiting pins prevent the waste package from being withdrawn beyond the shield).
5. Remotely open the lower door on the shipping cask.
6. Manually set restraints on lower door to prevent closing on the wireline.
7. Remotely open the blind ram inside the BOP shield.
8. Proceed to lower the waste package to emplacement position, verifying position using geophysical logs.
9. Disconnect cable head on electrical signal.
10. Hoist and re-spool wireline.
11. Remotely close the blind ram.
12. Manually release the restraints holding the upper and lower shipping cask doors open, and close the doors.
13. Repeat handling steps and steps 1 through 12 above, to emplace additional waste packages.

## CLOSING REMARKS

The conceptual designs of the two modes of handling and emplacing radioactive waste packages in deep boreholes were presented (updated drill pipe and wireline). These designs were used in a design selection study that compared the costs and risks associated with two handling and emplacement methods. The purpose of this work is to develop the designs, and not to evaluate the designs. That said, the reader may have noted two major differences between the emplacement modes: first, there is far more "stored energy" in the drill-pipe mode than in the wireline mode (e.g., 3,000 m of drill pipe could be accidently dropped onto emplaced waste packages during the tripout) and second, the wireline system will be much simpler to construct and utilize.

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