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 5 km (16,400 feet) deep for disposal. This paper describes three systems that can be used for handling and emplacing waste packages in deep boreholes: 1) a 2011 reference design in which waste packages are assembled into “strings” of up to 40 waste packages and then 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.

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 0.28 m (11 inches) and be approximately 5.7 m (18.5 feet) long. With an anticipated in-situ hydrostatic pressure of approximately 65 MPa (9,560 pounds per square inch) at total depth, the reference waste package will be made of steel with a 2.54 cm (one-inch) wall thickness. Despite the thick steel wall, the unshielded contact dose rate could be as high as several Sievert (several hundred rem) per hour.

The systems described here are currently designed for U.S. Department of Energy-owned granular high-level radioactive waste (HLW) materials, vitrified HLW, HLW in sealed capsules (i.e., the Cesium-137/Strontium-90) capsules from the Hanford Facility), and spent fuel. The waste forms to be considered in a future deep borehole waste disposal system are to be determined.

INTRODUCTION

For over 50 years deep borehole disposal (DBD) has been considered for disposal of radioactive waste [1]; however, 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) [2] 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. [3] and summarized below. For the anticipated operations, the reference design is to drill to 5 kilometers (km) (16,400 feet (ft)) with a 0.43 meter (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 the narrow borehole and very high down-hole pressures,[1] 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 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 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 design selection study is summarized in WM2016 paper entitled "Deep Borehole Waste Emplacement Mode Cost-Risk Study - 16346."

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

The assumed waste forms to be considered for the DBFT include 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. The waste forms to be considered in a future deep borehole waste disposal system are to be determined (TBD).

DESCRIPTIONS AND DISCUSSIONS

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).

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 [3] (for drilling and completion only).

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[1] 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 (16,400 ft) column.

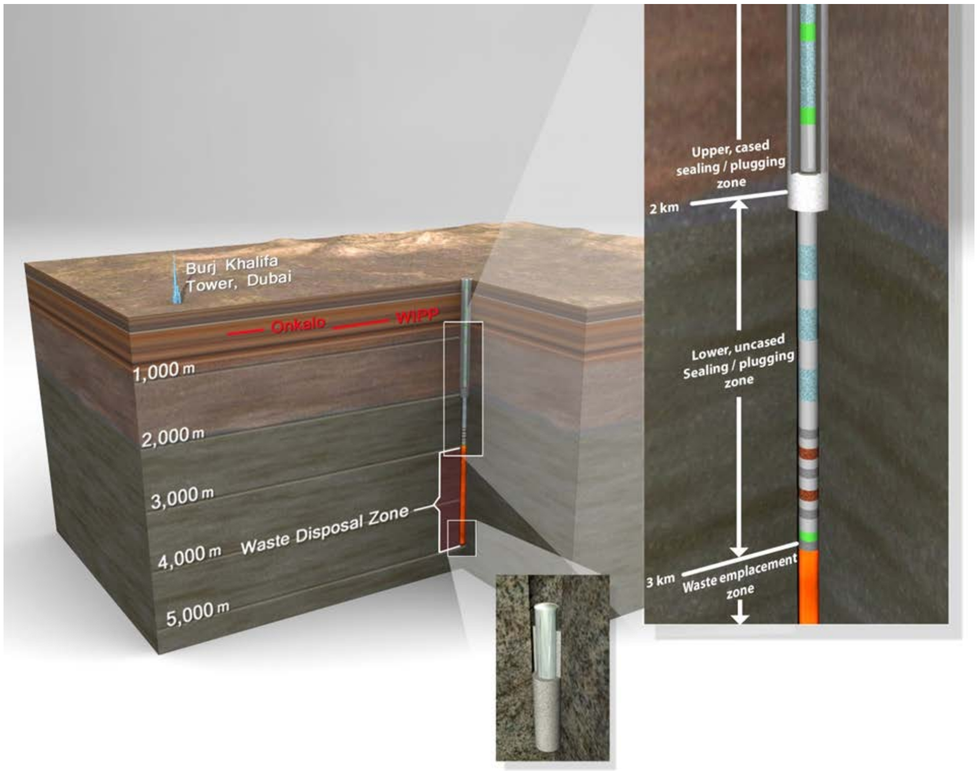

Fig. 1. Conceptual design of a DBD system. The dashed blue line indicates typical lower extent of useable fresh groundwater resources (from [4]).

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 to be conducted at full-scale, in-situ, without radioactive waste. 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 to the emplacement interval in the disposal borehole: lowering a string of waste packages using drill pipe and lowering single waste packages using a wireline. Both of these methods are developed later in this paper.

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 single 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 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 these factors: 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.

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, 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 an “elevator” ram can engage to support the package string during assembly as discussed below. All packages will have threaded ends for interface with other packages and an instrument package or emplacement equipment or an impact limiter. The threads will be standard drill pipe threads.

To accommodate various waste forms, the waste packages will have a maximum internal length of 5 m (16.4 ft), and the waste package length can be reduced by reducing the length of the tubular portion of the package. 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. The total maximum length will be 5.6 m (18.5 ft).

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 Sievert (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. [5] 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 (9,560 psi).

Because of the high pressures, high temperatures and narrow casing, traditional waste packages 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 [6] 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 2 and 3 show one of the four conceptual designs; in this case the 27.3-cm OD flask-type design.

It is estimated that the loaded waste packages will have a dry loaded maximum weight of 2,100 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 water.

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

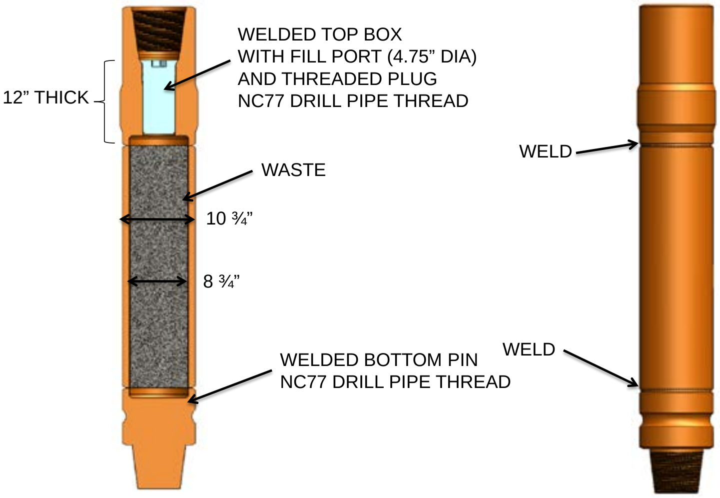

Fig 2. 27.3-cm (10.75-inch) OD flask-type design, aspect ratio shortened for illustration [6].

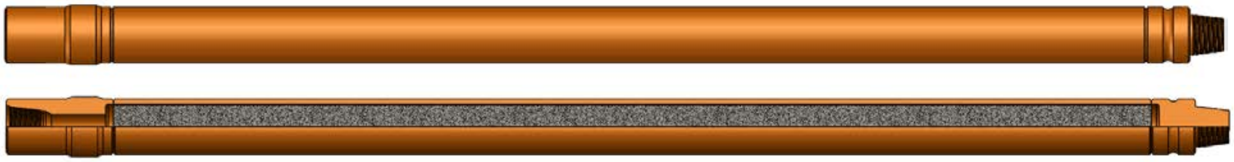

Fig. 3. 27.3-cm (10.75-inch) inch OD flask-type design, shown at true aspect ratio [6].

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 each Type B shipping cask. It is assumed that one waste package would be managed each day, based on operational experience with managing high-activity Class C low-level radioactive waste at the Waste Control Specialists (WCS) facility. At the WCS facility, it takes four days to complete a full emplacement cycle, but the Type B shipping cask can be unloaded and released in 24 hours [7].

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 shipping cask might have a flip-type top lid and a sliding door bottom lid with very thick steel doors, similar to that used in the Spent Fuel Test - Climax [8]. 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 detail by Cochran and Hardin [9]. In the drill pipe design, waste packages are assembled in the top of the borehole into a string of up to 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 may be 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 for the waste packages 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 being 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 [3] is based loosely on a 1983 Woodward–Clyde study [10], which itself is based on the Spent Fuel Test-Climax (SFT-C) at the Nevada National Security 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 assemblies were stored underground for three years, and then retrieved through the same borehole [11].

In the 2011 presentation of this design, the waste packages are assembled within the top of the borehole into a string of up to 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 [3], and summarized by Cochran and Hardin [9] and are not repeated here.

Updated Drill Pipe 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 of 0.43-m (17-inch) diameter in the disposal interval, but similar facilities would be used for disposal boreholes of different sizes**.**

Basement construction – Waste packages will be assembled into a string of up to 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) to provide a shielded facility to assemble the waste packages into strings of waste packages and to house the blow-out preventer (BOP); and 2) to reduce the height requirement for the emplacement rig, and related equipment. The basement structure will need to withstand loading at the ground surface by the emplacement rig.

Figure 4 shows a cutaway of the basement, which could be up to 9 m (30 ft) deep. The basement contains power tongs for rotating (assembling) 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 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 1983 Woodward-Clyde concept [10], 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.

Emplacement workover rig setup – The emplacement rig will used in conjunction with the equipment in the basement to assemble waste packages into strings of waste packages, 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

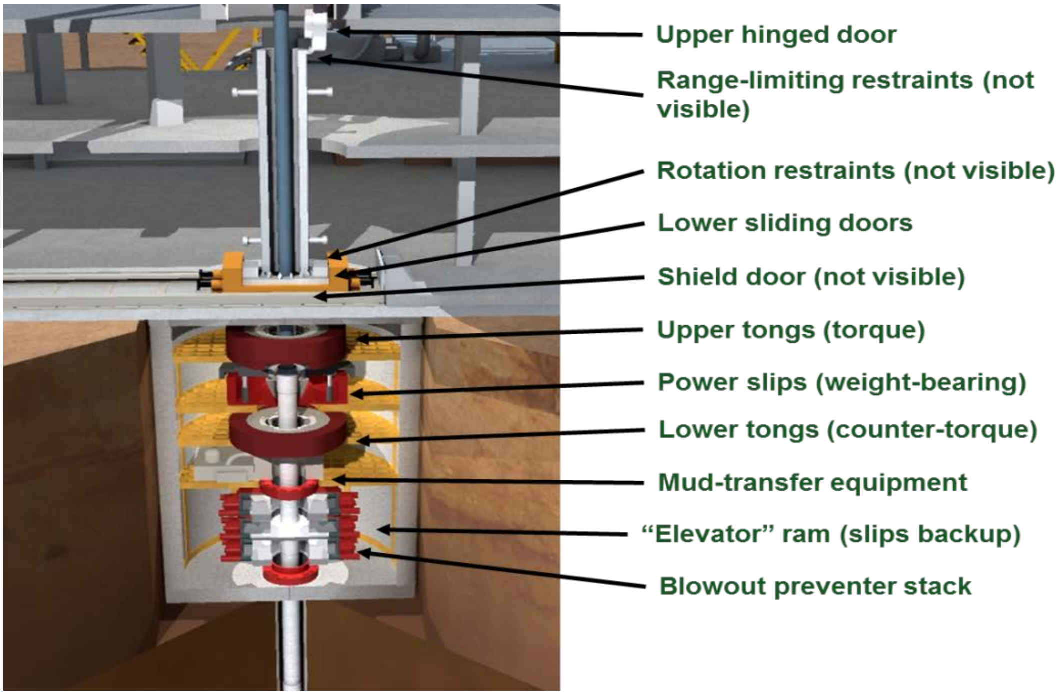

Fig. 4. Shielded "basement" equipment for handling waste packages.

lift; the heaviest lift 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.

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

<u>Ancillary equipment</u> - Ancillary equipment associated with the emplacement rig will include generators, pipe handling, an iron roughneck, 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 will be 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 waste package to take weight off lower door of shipping cask.
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 in the basement, 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 of the BOP.
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 power slips and “elevator” ram, engage 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 top of basement and doors on the shipping cask.
19. Reverse handling steps to remove shipping cask.
20. Repeat handling steps and steps 1 through 19, to add additional waste packages to the string.
21. After final waste package is added to the string of packages, 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 connection 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 an “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 5). After waste emplacement, a completion/sealing workover rig will be used for final sealing and plugging.

Surface pad – A steel-reinforced concrete pad, approximately 8.2 m (25 ft) on a side, will be poured around the wellhead at grade level, as a base for the BOP shield and other items.

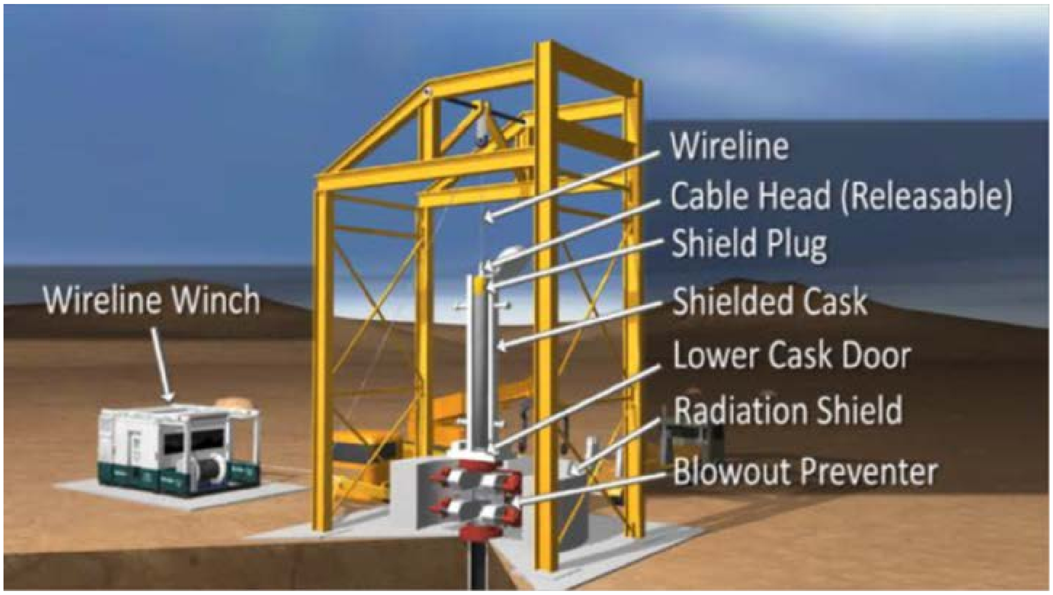

Fig. 5. Wireline handling and emplacement components.

BOP shield – A robust radiation shield will be constructed around the BOP (Figure 5). 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 (not shown in Figure 5).

Hoist and wireline – A standard truck- or skid-mounted wireline with 6,100 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). However, coiled tubing fatigue and safety are 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 250,000 kg [550,000 lb]) 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 associated with the hoist.

Handling Steps

All systems (drill pipe or wireline) will be tested after fabrication, and on-site with empty ("dummy") waste packages prior to operations. Standard operating procedures, staff training and qualification requirements, maintenance procedures, and contingency procedures will be developed.

Before the shipping cask is placed over the borehole, a caliper log will be run to the 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 top of 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 shielded shipping cask).
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.

CONCLUSIONS AND OBSERVATIONS

The conceptual designs of the two modes of handling and emplacing radioactive waste packages in deep boreholes were developed here and detailed in Cochran and Hardin [9]. Although this paper is not an evaluation of the two designs,[2] three key observations can be made about the emplacement modes: 1) there is far more "stored energy" in the drill-pipe mode than in the wireline mode (e.g., 3,000 m of drill pipe, accidently dropped onto emplaced waste packages, might have enough stored energy to breach a package); 2) the wireline emplacement mode would require ~ 40 times more trips to the emplacement zone than the drill-pipe emplacement mode and 3) the wireline system will be much simpler to construct and utilize.

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ACKNOWLEDGEMENTS

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. SAND2015-9713 C.

Many thanks to Scott Kirk for hosting a tour of WCS's system for managing Type B shipping casks that contain high-activity LLW.