Conceptual Design of the Package Handling System for the Deep Borehole Engineering Demonstration – 17064

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ABSTRACT

Deep borehole disposal involves drilling one or more boreholes into crystalline basement rock to a depth of about 5 km, emplacing waste packages in the lower 2 km of the borehole, and sealing and plugging the upper 3 km. These depths are several times deeper than for typical mined repositories.

A deep borehole field test (DBFT) is proposed to confirm the safety and feasibility of the deep borehole concept. The primary goals are to demonstrate the construction and characterization of deep boreholes, demonstrate the equipment and operations used for safe waste handling and emplacement downhole, study geologic controls on waste form stability and isolation, and evaluate the overall safety and practicality of the concept. The test will be conducted using simulated waste packages; no radioactive wastes will be handled at the deep borehole field test site.

A key component of the DBFT is an engineering demonstration of the equipment and operations needed to transport waste packages to the site, move packages between the transportation and emplacement systems, and lower or retrieve packages into or out of the borehole.

This paper describes the conceptualization of test package handling, from transportation and receipt through the interface with the borehole. It also describes the use of an integrated test facility to check out equipment prior to deployment at the DBFT site, and performance of the engineering demonstration at the DBFT site.

INTRODUCTION

The general concept for deep borehole disposal (DBD) consists of drilling one or more boreholes into crystalline basement rock to a depth of about 5 km, emplacing waste packages in the lower 2 km of the borehole, and sealing and plugging the upper 3 km. Waste forms that might be considered for DBD include high-level waste materials in sealed capsule forms.

The Department of Energy is planning a deep borehole field test (DBFT) to demonstrate the construction and characterization technology needed for DBD. The DBFT plan includes drilling a characterization borehole and a larger field test borehole, and includes an engineering demonstration of the receipt, handling, emplacement, and recovery of a test package. The test will be conducted using simulated waste packages; no radioactive wastes will be handled at the deep borehole field test site. Key objectives of the engineering demonstration are highlighted in Fig. 1.

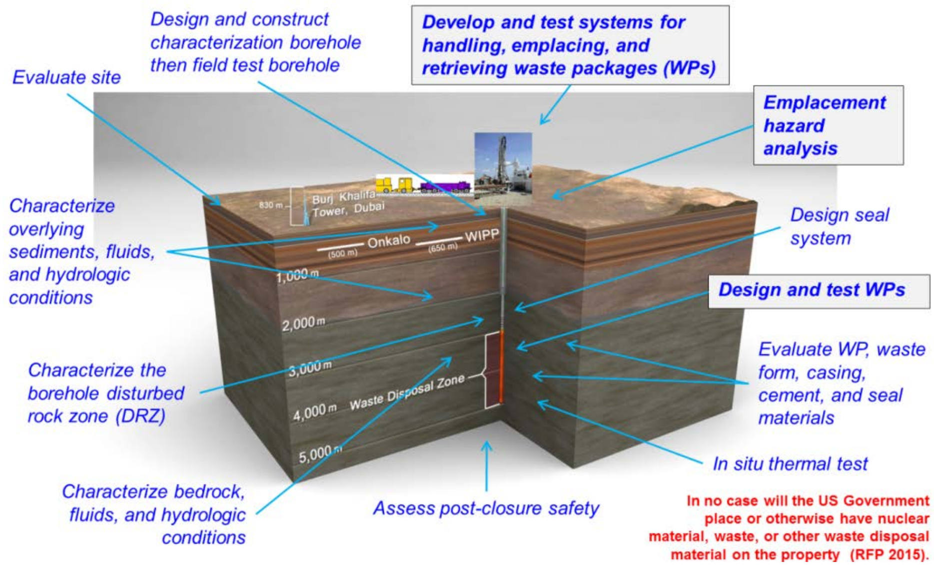

Fig. 1. Borehole concept highlighting engineering demonstration objectives.

A range of emplacement methods have been studied [1-4], including the use of an electric wireline and a string of drill pipe. The wireline method was selected on the basis of simpler operation and lower anticipated risk. The key features of a wireline emplacement system are shown in Fig. 2. This system would be based on wireline technology presently utilized in oil and gas drilling, such as is offered by Schlumberger Ltd. [5] and Halliburton.

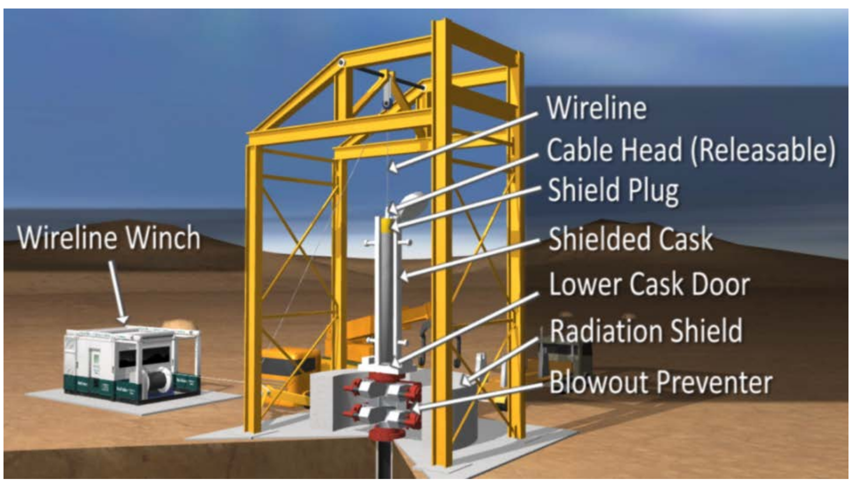

Fig. 2. Depiction of wireline emplacement system.

Designs of the characterization and field test boreholes have also been evaluated. The largest borehole system considered achievable with existing technology will be used for the field test. The casing design for this borehole is shown in Fig. 3, with an internal guidance casing diameter of 340 mm (13-3/8”).

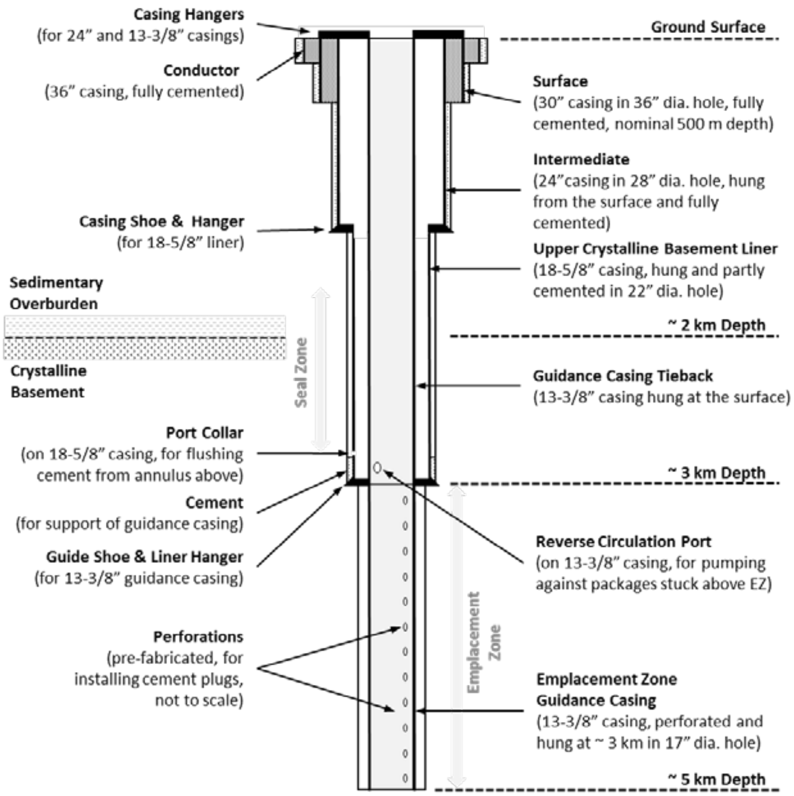

Fig. 3. Reference casing dimensions for the field test borehole.

Waste forms that might be considered for DBD include sealed capsule forms. Encapsulated salts of ^{137}Cs and ^{90}Sr stored at the Hanford Waste Encapsulation and Storage Facility are well documented, highly radioactive, and thermally hot. A universal canister has been described [6] to handle this waste form. A reference package based on these universal canisters is shown in Fig. 4.

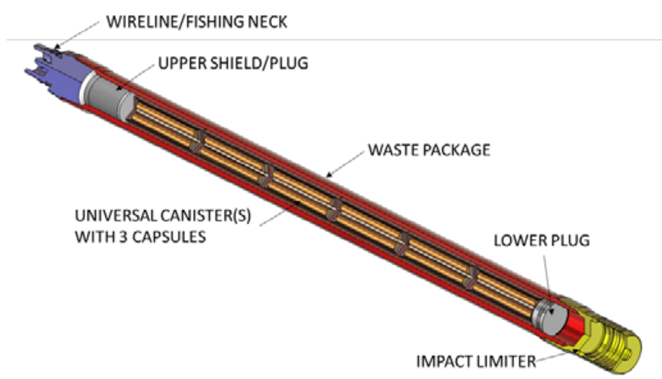

Fig. 4. Reference package based on encapsulated waste in universal canisters.

DISCUSSION

Conceptual Design Basis

As described above, the basis for the conceptual design of the package handling system is the wireline method, using a field test borehole and a waste package consistent with the use of the universal canister and the diameter of the field test borehole guidance casing. The diameter of the waste package is limited to about 315 mm by the internal drift of the casing, and its length is to be defined later.

The conceptual design will be based on contracted use of an existing electric wireline system, include cable handling systems and electrically-operated remote disconnects. Although the disconnect is commonly part of a tool string that might be left downhole so the cable may be recovered, for this application the disconnect will be inverted so it is withdrawn for reuse after the package is placed in the borehole.

The conceptual design of the package handling system identifies equipment for package transportation and receipt, package handling at the borehole site, connection of the handling system to the borehole, the interface to an existing wireline system, and the support systems needed for package handling system operation. Package design is not in the scope of the handling system, but the design of the handling system influences package design. Rail access to the field test site is not assured, so a truck-based transportation system is preferred. Borehole completion is not in the scope of the handling system, but definition of reference equipment is needed to establish interface requirements.

The engineering demonstration will be performed on an actual borehole, but will not use radioactive waste. Some components may be mocked up for the demonstration to reduce cost and aid in early implementation. This results in a two-step process; first the equipment needed for actual waste emplacement is conceptualized, then a simplified version that meets test objectives is designed. The test equipment must be appropriate for use on an actual borehole, and must meet all requirements for fluid control and operational safety. However, shielding and other aspects related to radiation and contamination control may be modeled in mockup form.

An integrated test facility (ITF) is recommended to allow initial testing of equipment in a controlled shop environment. The ITF should allow checkout of integrated operation to the greatest extent practical without a deep borehole. Mobilization at the field test site will proceed promptly after ITF testing is complete. The field test will, at a minimum, place and retrieve a single test package, and place (and recover) an instrumented test package. Equipment will be dispositioned following completion of the field test. Sealing or plugging the borehole is not within the scope of the demonstration, but the design must accommodate such operations.

Borehole Completion

A reference for completion of the field test borehole is shown in Fig. 5.

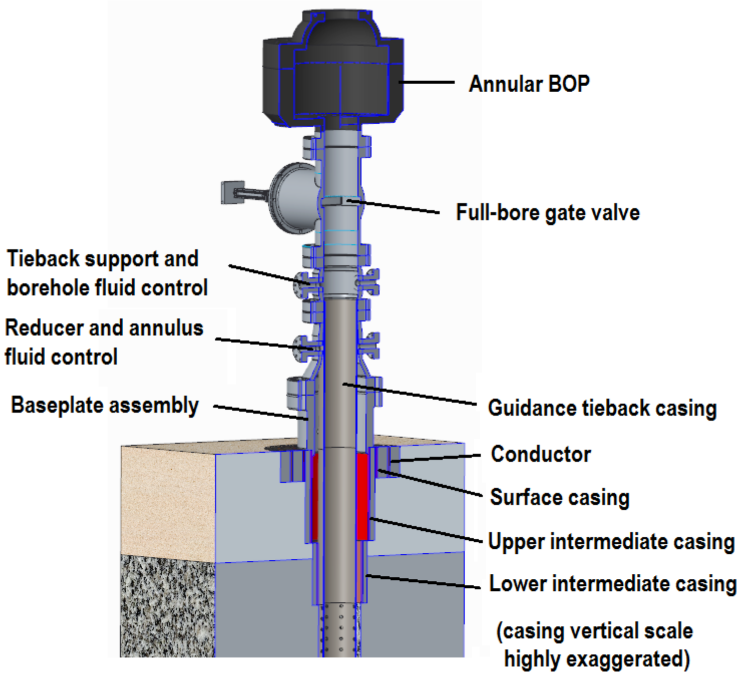

Fig. 5. Reference field test borehole completion components.

The conductor, surface casing, and upper intermediate casing are presumed to be complete and cemented by the drilling contractor. A baseplate assembly is set on the cemented upper intermediate casing, and a reducer, with fluid control taps used to control casing annulus fluid, is connected to the baseplate. The guidance tieback is welded to a tieback support spool piece that is provided with connections for borehole fluid control.

A full-bore gate valve is mounted above the tieback support, allowing closure of the borehole under normal conditions. Blowout preventer (BOP) requirements will be set by state regulations and actual field conditions. Because no changes are made to the borehole after completion, it is presumed that a single annular BOP will be acceptable. This type of BOP can close over an open hole, a wireline, or a test waste package without significant risk of damage. The completion equipment will be in a pit, such that a radiation shield can be placed at grade level.

Transportation Cask

To enable timely completion of the demonstration, an existing truck-based cask appropriate for a long package is desired. Although a double-ended cask would be preferred, no such licensed cask was identified.

A legal weight truck (LWT) Type B cask, such as provided by NAC International, Inc., was selected as the reference for this conceptual design. The internal cavity diameter of NAC's LWT is 340 mm, very close to the diameter of the guidance casing. This cask has been used extensively in the DOE complex; Fig. 6 shows it being set in a cradle at an Oak Ridge National Laboratory (ORNL) fuel examination facility. Although the certificate of compliance [7] would be revised for actual use, it should be available for a demonstration without radioactive material.

Fig. 6. LWT cask from NAC International set on cradle at ORNL.

The cavity length of NAC's LWT is 4.52 m. This length, along with the diameter limited by borehole drift and cask cavity diameter, defines the test package.

Transfer Cask

Because no double-ended transportation cask is available, test packages will be handled using a purpose-designed on-site transfer cask. The overall configuration of the transfer cask is similar to an LWT cask, with an internal cavity sized to test package dimensions. Top and bottom shield plugs will be defined in following sections, based on operational requirements. A sketch of the transfer cask is shown in Fig. 7.

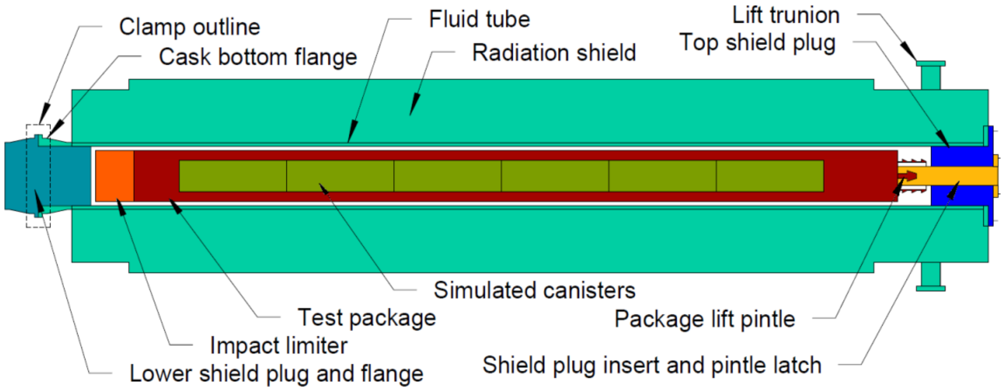

Fig. 7. Transfer cask and test package, depicting universal canisters.

Calculations show that a waste package containing six universal canisters with three Hanford capsules each would be adequately shielded with 350 mm of steel [1,8]. This calculation also suggests the LWT cask from NAC International would provide adequate shielding for the reference package.

For the engineering demonstration, a cask mockup might include an inner fluid pipe, top and bottom shield plugs, lift trunions and support plates that provide adequate support, and possibly a space frame to represent radiation shielding.

Borehole Pit and Shield

Shielding must be provided as the package is lowered out of the transfer cask into the borehole. A shield system that allows maintenance or recovery of a misaligned package under the transfer cask is also desired.

A system of sliding plates and rotating plugs has been used for a range of operations at ORNL’s Molten Salt Reactor Experiment, as shown in Fig. 8. This system allows positioning of tools at desired positions, using multiple tool plugs. An adaption of this concept would allow positioning of the transfer cask over the borehole, as well as support necessary maintenance or recovery activities.

Fig. 8. Maintenance shield with rotating plugs used at ORNL.

The pit shield proposed in this design would have an opening in a central rotating plug, sized to accept the transfer cask in a vertical orientation. A second large opening, normally plugged, would accept the largest equipment item in the borehole pit. Secondary plugs would be provided for tooling, as seen in Fig. 8. The shield system would allow rotation of the transfer cask to a lower shield plug removal station, and accurate positioning of the cask over the borehole. A jacking system would gently lower the cask onto the borehole top flange.

The pit shield would be designed to support the weight of the transfer cask over the borehole pit, and may involve a central support post. A steel thickness of about 12 inches is anticipated. For the engineering demonstration, lighter mockup materials may represent shielding, but the system must support all required loads.

Transfer Cask to Borehole Interface

For fluid control purposes, a seal must be established between the central fluid tube of the transfer cask and the borehole guidance casing. This implies a flange connection beneath the borehole pit shield. A remotely-operated clamp system, such as provided by the Grayloc unit of Oceaneering International Co., is available in the size needed. This system, shown in Fig. 9, uses a lead screw to secure a clamp around two flange surfaces. A remote drive would operate the lead screw.

Fig. 9. Remotely-operated flange clamp.

Since the engineering demonstration will be performed on an actual borehole, fluid control is required as with a disposal system. A pit configuration with an annular BOP, a transfer cask set in a top shield plate, and a remote flange system is shown in Fig. 10.

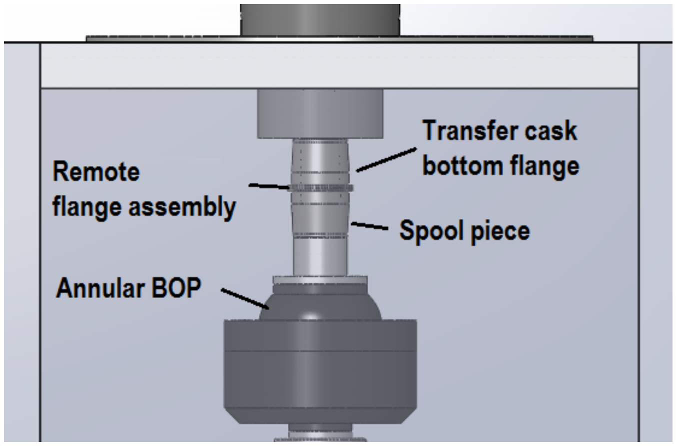

Fig. 10. Coupling of transfer cask to reference borehole system.

The clamp operating mechanism is permanently attached to the bottom of the transfer cask, and is also used to secure the lower shield plug to the cask.

Transfer Cask to Transport Cask Interface

Packages are received at the disposal site in a transportation cask, and transferred into the double-ended transfer cask prior to being placed over the borehole. This is accomplished with both casks horizontal in cradles (as shown in Fig. 6) using an interface shield. The interface consists of a fixed shield frame and a sliding slab shield, as shown in Fig. 11.

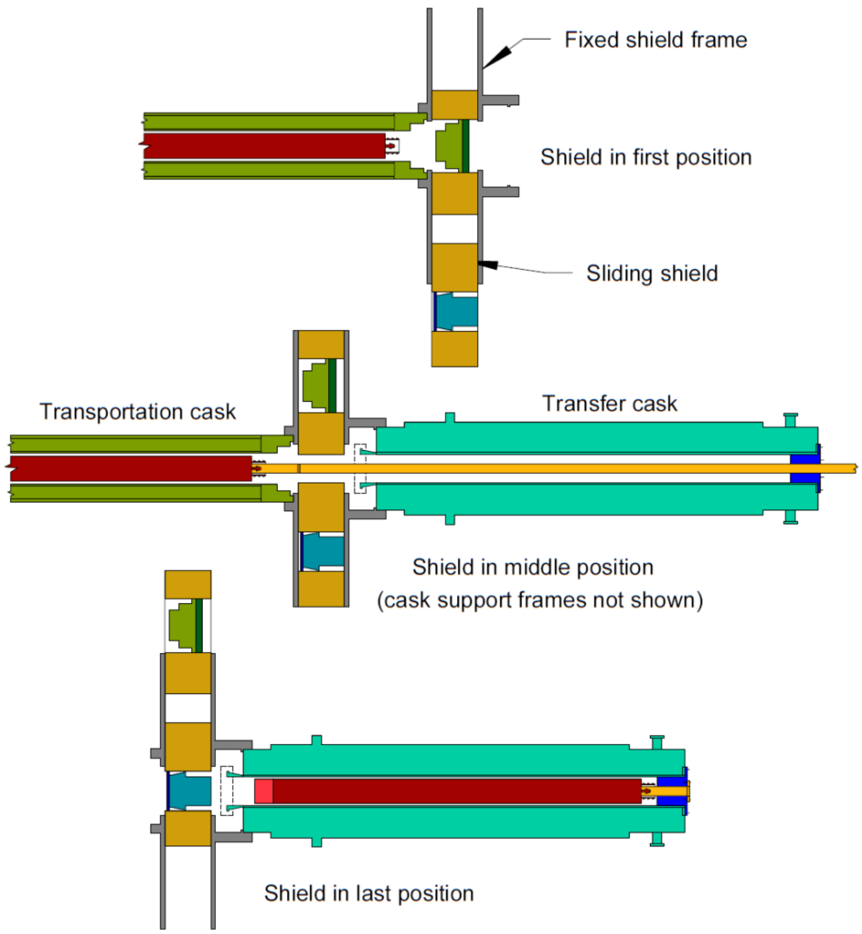

Fig. 11. Operating sequence for the cask interface shield (top view).

With the shield in the first position, the transportation cask is moved into position and the shield plug is disconnected and withdrawn into the sliding shield slab; a jig may be used to maintain orientation and the shield plug continues to provide shielding for operators. The transfer cask is then moved into position, and the slab is moved into its middle position, open to both casks.

The top (right) shield plug on the transfer cask includes an inner shaft and latch assembly. A shaft extension is attached, and the latch is moved into position on the package. The package is pulled into the transfer cask and the shaft extension is replaced by a screw-on flange, which is secured onto the top shield plug.
The shield slab, with the lower transfer cask plug pre-positioned, is slid to its last position. With the plug providing shielding for the operators, the empty transportation cask is moved away and the transfer cask plug is pushed into the transfer cask. The remotely-operated clamp is actuated to secure the plug, and side pins (not shown) are inserted into indents in the package. The transfer cask is now ready to be moved into position over the borehole.

Wireline and Fluid Seal Components

The tool string coupling the electric wireline (with internal electric conductors) to the package consists of the electric disconnect, a position indicator, and a wireline cable head. Conductors pass through the cable head and position indicator, ultimately providing power to the package disconnect. The attachment of the cable to the cable head is constructed such that upon excessive loading, the cable would pull out of the head rather than the breaking the cable at an undetermined point. The electric package disconnect would be oriented so that it remains on the tool string after the package is released. These components are identified in Fig. 12.

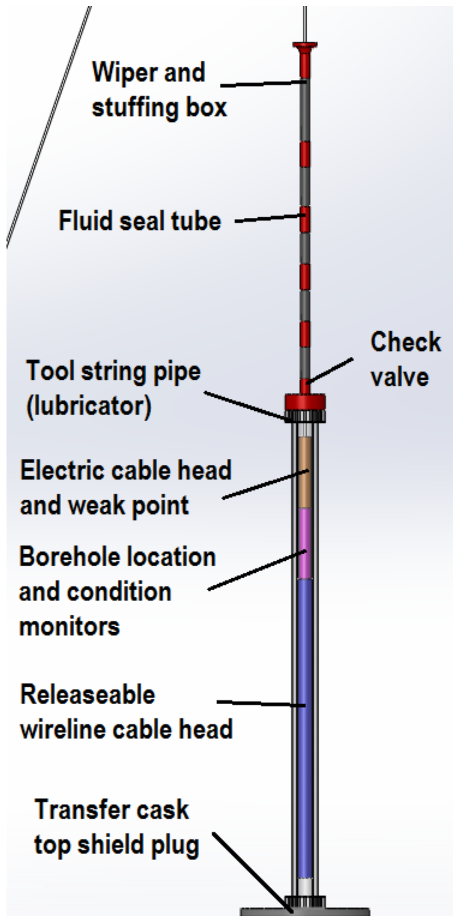

Fig. 12. Reference tool string and fluid seal components.

The possibility of positive fluid pressure in the borehole exists. A strong pressure surge would trigger closure of the BOP, but a modest, continual pressure would fill the borehole and transfer cask with fluid. For emplacement, the cask must be open to the borehole, and a fluid seal is needed at the top of the cask. A fluid control tube, commonly called a lubricator, is mounted on top of the cask. Typical practice is to seal the wireline with a closely-fit greased seal tube, with a stuffing box on top of the tube. The stuffing box is eased to allow cable movement; if fluid leakage becomes problematic the cable is stopped and the stuffing box closes on the cable.

Modifications to this tool string and fluid control system would allow use of a gauge ring and junk basket to verify borehole conditions prior to package placement (without the transfer cask), and use (with the transfer cask) of a fishing tool to capture a package and return it to the transfer cask.

Emplacement

The assembled placement system, including pit shield, transfer cask, tool string and lubricator, wireline seal, and wireline sheaves is shown in Fig. 13. Supporting systems include electric power, water, a borehole fluid management system, and instrumentation with an interlock system and a data display and control station. Site features include pads for trucks, a crane, a headframe (the crane could be used for the demonstration), a decontamination station, and the necessary personnel support systems.

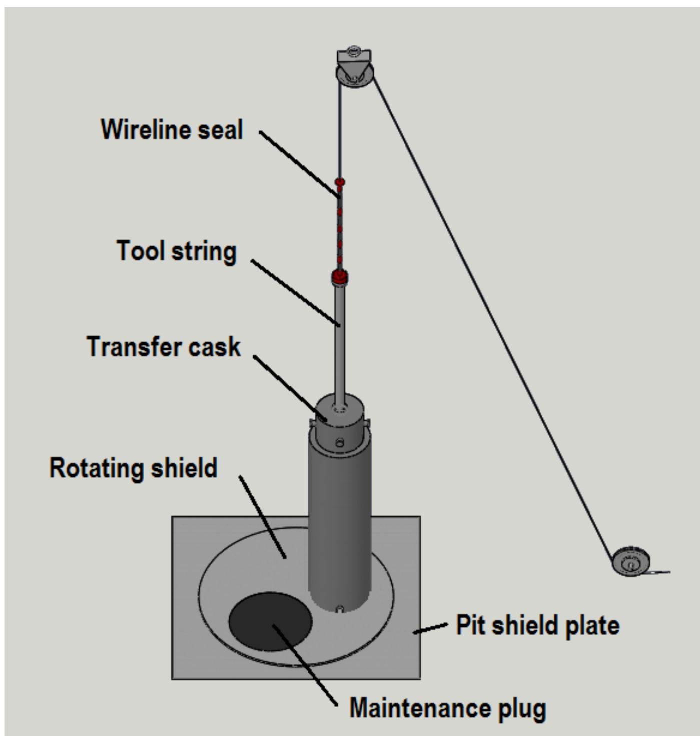

Fig. 13. Depiction of transfer cask and wireline components over borehole.

Integrated Test

Individual components used for the demonstration will be either industry-standard rented equipment or will be custom designed and tested at the fabrication site. Performing an integrated test in a controlled environment with on-site shop capabilities allows checkout of interfaces, data collection, and interlocks prior to deployment at a remote borehole site. A potential integrated test arrangement is depicted in Fig. 14.

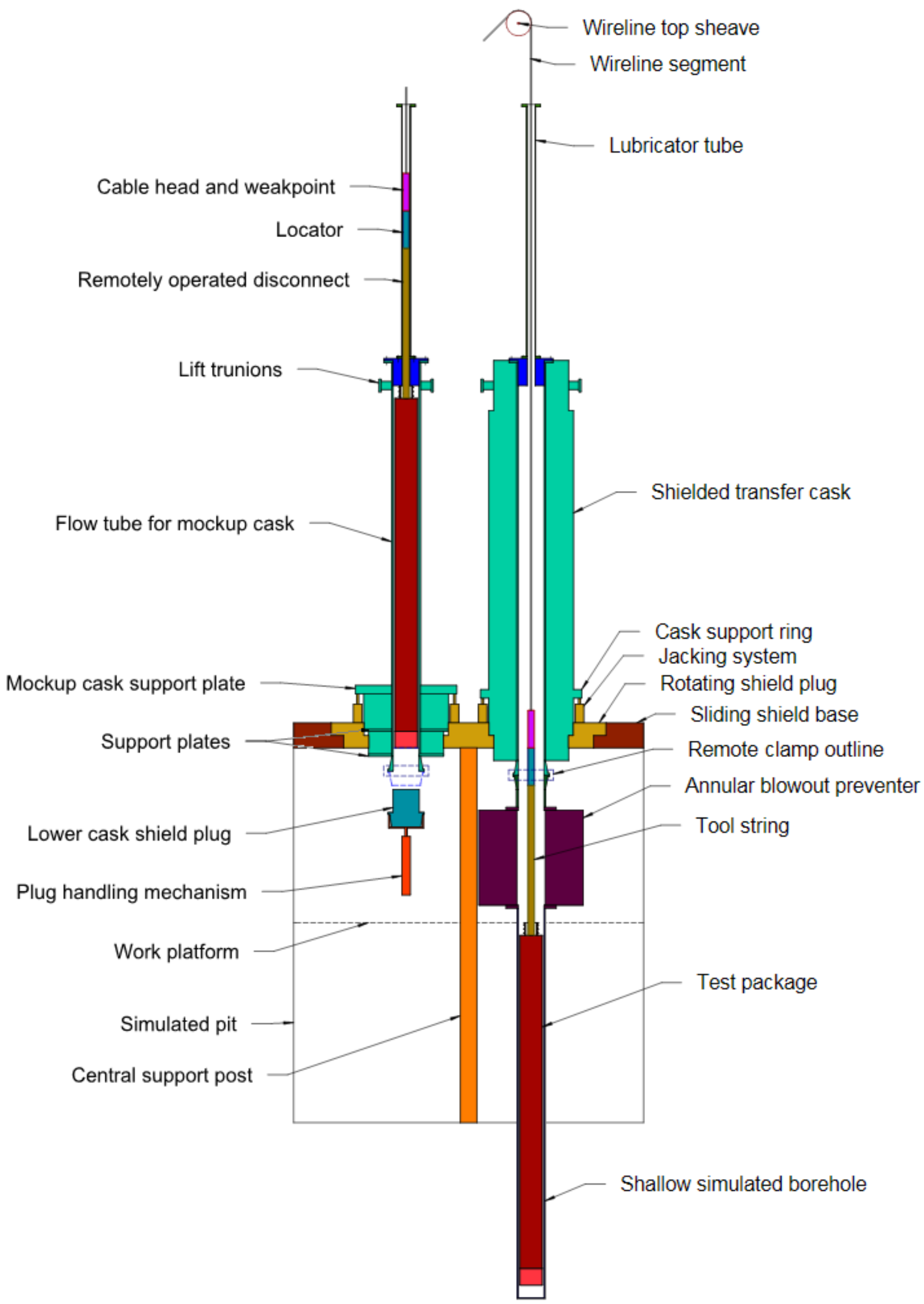

Fig. 14. Integrated test of the reference engineering demonstration components. Fig. 14 depicts a minimal borehole mockup, with a BOP and spool piece allowing practice with the lower flange. It includes a short simulated borehole in which the test package can be lowered beneath the BOP; a slightly deeper hole would allow transit of the entire tool string beneath the borehole. The figure depicts the borehole and the lower plug removal stations; these would actually be 120˚ apart with a third maintenance access position. The transfer cask image on the right is for the actual cask; the image on the left depicts the minimal mockup structure

required to demonstrate key interfaces. Only a short wireline segment is required, and the fluid seal is not in present scope (although a stuffing box might be added).

A pad is also provided at the ITF for demonstration of the interface shield used to transfer packages from the transportation cask to the transfer cask. Rented equipment, including the actual wireline system, may be collected and inspected at the ITF prior to mobilization at the field test site. Equipment would then be moved to the field site immediately upon completion of integrated test objectives.

Engineering Demonstration at Field Test Borehole

The actual engineering demonstration at the field test borehole site will be performed when drilling and characterization activities (under a separate contract), package testing activities (again, a separate scope), and shop and integrated testing of package handling equipment are complete. Pending experience and data from the initial characterization borehole, the field test borehole will be completed as described in Fig. 3. The pit and shield interface will be constructed, and borehole completion equipment will be installed. The site will be graded and gravel pads, or when necessary paved pads, will be constructed. A sense of the borehole site plan is provided in in Fig. 15. Support systems, including borehole fluid control, wireline trucks, utilities and instrumentation, and personnel support, are also required.

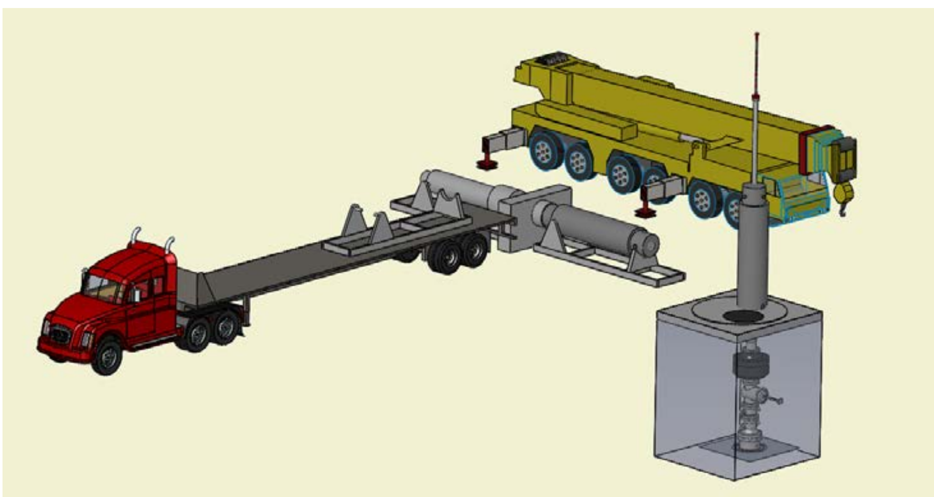

Fig. 15. Depiction of engineering demonstration at the field test borehole site.

The minimal requirements for the demonstration include placement of one or more test packages, retrieval of a test package that has previously been released from the wireline, and placement and retrieval of an instrumented test package. The sequence for placement of test packages is as follows:

- Mobilization at the field test borehole site
- Borehole completion, including setup of the pit shield
- Setup of supporting infrastructure
- Receipt of engineering demonstration equipment, including rentals

- Demonstration of borehole condition verification
- Demonstration of package receipt (using a rented cask and pre-tested package)
- Demonstration of package transfer to the transfer cask
- Positioning of the transfer cask over the borehole pit
- Installation of the tool string and fluid control system through the top shield plug
- Removal of the lower shield plug
- Rotation to the borehole position and clamping onto the borehole top flange
- Lowering and release of the package
- Retrieval of the wireline and tool string
- Removal of the transfer cask and closure of the borehole
- Cleaning of the transfer and transportation casks
- Preparations for receipt and placement of the next package

The operating sequence for package retrieval is similar, but in many ways the reverse. Rather than the remotely operated disconnect, a fishing tool will be added to the tool string. Modifications to the top shield plug may be required to adapt to the retrieval tool string. Running a gauge ring and junk basket prior to package emplacement may be accomplished with a simpler lubricator and fluid control arrangement attached directly to the borehole flange through the pit shield.

The demonstration will likely include performance of various equipment inspection and maintenance activities, and recovery from select upset conditions. These activities have not yet been identified. At the completion of the demonstration, the test equipment will be removed from the site and the borehole will be returned to a site contractor.

CONCLUSIONS

This paper depicts the conceptual design and preliminary test plan for the package handling equipment necessary to demonstrate package emplacement and recovery in a deep borehole. The concept shows that familiar equipment and procedures can be used for package handling, and no exceptional challenges are anticipated. The challenges that do exist are associated with the borehole itself, including downhole operations and control of borehole fluid. There remain many details to resolve, including careful modeling of radiation shield performance and development of operating mechanisms such as the package latch and bottom flange.

An integrated test is recommended to resolve uncertainties prior to site mobilization, allowing final checkout of integrated operation in a shop environment.

Other factors, including the specific characteristics of the field test site, will influence the final design of the handling systems. Potential impacts range from modified layouts and handling paths to the possible use of the smaller characterization borehole for the demonstration.

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