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CONCEPTUAL DESIGN FOR WASTE PACKAGING AND EMPLACEMENT IN DEEP BOREHOLES

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The Deep Borehole Field Test will include demonstration of the emplacement and retrieval of test waste packages (containing no waste) in a 5 km deep borehole drilled into the crystalline basement. A conceptual design for packaging, surface handling and transfer equipment, and borehole emplacement was developed in anticipation of the demonstration project.

Test packages are designed to withstand external pressure greater than 65 MPa, at temperature up to 170°C. Two packaging concepts were developed: 1) flask-type for granular waste, and 2) internal semi-flush type for waste that is pre-canistered in cylindrical containers. Oilfield casing materials and sealing connections would be selected giving a safety factor of 2.0 against yield. Packages would have threaded fittings top and bottom for attachment of impact limiters and latch fittings.

Packages would be lowered one-at-a-time into the borehole on electric wireline. This offers important safety advantages over using drill pipe or coiled tubing to lower waste packages, because it avoids the possibility of dropping a heavy assembly in the borehole. An electromechanical latch would release each package, or reconnect for retrieval.

Frequency of waste package delivery to a disposal site could be the effective limit on emplacement throughput. Packages would be delivered in a shielded Type B transportation cask and transferred to a shielded, double-ended transfer cask on site. The transfer cask would be upended over the borehole and secured to the wellhead. The transfer cask would become an integral part of the pressure control envelope for well pressure control. Blowout preventers can be incorporated as needed for regulatory compliance.

Operational safety has been assessed with respect to normal operations, and off-normal events that could cause package breach in the borehole. Worker exposures can be limited by using standard industry practices for nuclear material handling. The waste packages would effectively be robust pressure vessels that will not breach if dropped during surface handling. The possibility of package breach in the borehole during emplacement can be effectively eliminated using impact limiters on every package.

I. 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 (WPs) in the lower 2 km of the borehole, and sealing and plugging the upper 3 km. Waste forms being evaluated technically for DBD include relatively small-volume, defense-related high-level waste (HLW) streams.

The U.S. Department of Energy (DOE) 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 (CB) and a larger field test borehole (FTB), and includes an engineering demonstration of the packaging, handling, emplacement, and recovery of test packages. Details of the DBD safety strategy and the field test plans have been described.[1] The engineering demonstration will be conducted using simulated WPs; no radioactive wastes will be delivered to or handled at the DBFT site. However, the demonstration will closely resemble the DBD concept to the extent practical. This paper describes the conceptual design for packaging waste, and for handling and emplacing WPs in deep boreholes, that will be used for the demonstration.

II. DBD SYSTEM CONCEPTUAL DESIGN

II.A. Borehole Drilling and Completion

Designs for the CB and FTB have also been developed.[2,4] The diameter and casing plan for the FTB (Fig. 1) represents the largest diameter (43 cm) that is considered to be achievable for 5 km depth in crystalline rock with existing technology.

The FTB wellhead will be completed by the drilling contractor (Fig. 2). The conductor, surface casing, and intermediate casing will be installed and cemented during drilling. The wellhead assembly will hang both the intermediate casing and the guidance casing tieback, and reduce diameter to that of the guidance casing.

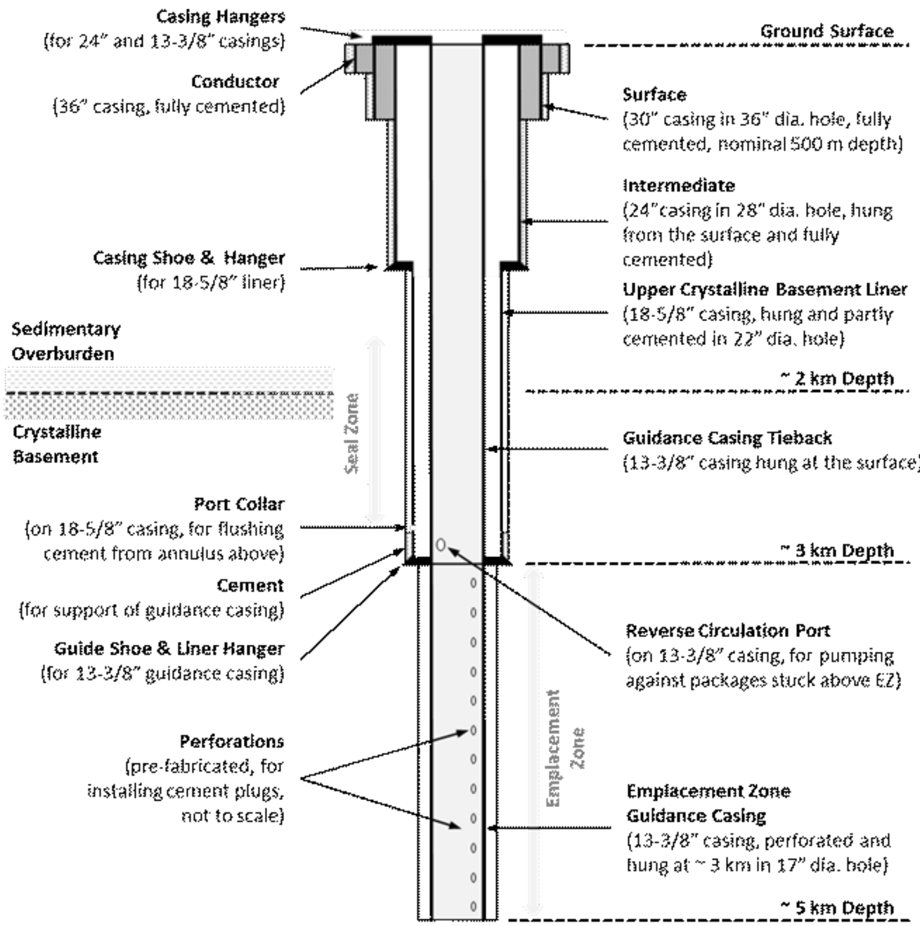

Fig. 1. Reference diameter and casing plan for the FTB, for the DBFT.

Fluid control taps will control the annuli, and a full-bore gate valve will be mounted on the guidance casing for control under normal conditions. It is assumed that a single annular blowout protector (BOP) will be acceptable to permitting authorities. This type of BOP can close over an open hole, a wireline, or a test waste package without significant risk of damage. The wellhead shown in Fig. 5 will be entirely enclosed within a pit, with a radiation shield above the wellhead, at grade level.

II.B. Waste Forms and Packaging Options

Waste forms to be disposed of in deep boreholes are identified for the purpose of designing the DBFT engineering demonstration. Waste forms to be considered for the DBFT include granular HLW materials, and HLW in sealed capsules. Two basic waste packaging concepts are presented: 1) flask-type packages for bulk waste (such as granular calcine waste), and 2) internal semi-flush packages for pre-canistered waste (such as the Hanford Cs/Sr capsules).

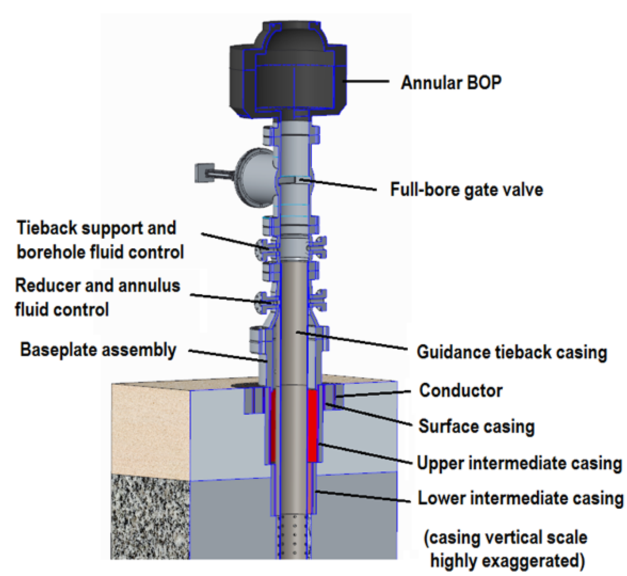

Fig. 2. Reference FTB completion components.

Suitable materials, connection types, and fabrication services are available in vendor offerings to the oil and gas industry. Simple packaging concepts of each type were developed, and numerical stress analysis was performed for the projected downhole environment to verify adequate margins of safety against containment failures.

Small, medium, and large WP concepts were developed for maximum downhole hydrostatic pressure of 65 MPa, and maximum temperature of 170°C. Compliance with these specifications was determined from: 1) numerical stress analysis, and 2) vendor pressure ratings for threaded connections at the ends. Threaded connections would serve as attachments for a wireline latch and fishing neck, and an impact limiter on each package (Fig. 3). The outer connection at the upper end would also serve as backup for the internal threaded connection on the fill plug used to load WPs. Selection of materials for WPs to be used for disposal will also need to consider containment lifetime in the expected downhole environment (e.g., hot brine).

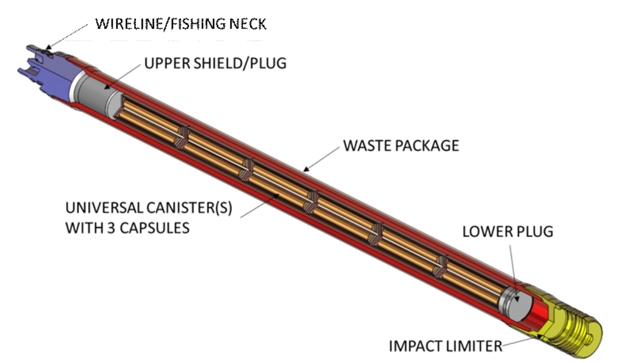

Fig. 3. Reference package to accommodate Hanford Cs/Sr capsules in canisters of three, loaded end-to-end.

II.C. Wireline Emplacement Method

Several methods for emplacing WPs at the bottom of a 5-km borehole were considered: free-drop, electric wireline, coiled tubing, drill-string, and conveyance casing (on a drill string). The free drop method was judged to be impractical, but the behavior of WPs that are accidentally dropped in a disposal borehole was extensively analyzed. Wireline emplacement was selected as the preferred option for the DBFT engineering demonstration, based on consideration of safety and cost. The key features of a wireline emplacement system are shown in Fig. 4. Wireline emplacement is made more attractive by the availability of modern wireline cable and tools, and the use of an impact limiter on every WP.[2,3]

Probabilistic risk assessment was used to compare the wireline and drill-string methods. The likelihood for any off-normal event that could cause a WP to breach in the borehole releasing radioactivity, was estimated to be less than 0.002% per borehole with 400 WPs, for wireline emplacement. This kind of reliability is possible with use of an impact limiter (Fig. 5) on every WP to mitigate consequences if a package is accidentally dropped. The probability of package breach for drill-string emplacement (i.e., using a drill rig and lowering strings of packages on drill pipe) was found to be approximately 400 times greater because of the risk from dropping much heavier assemblies of consisting of waste packages and/or drill pipe.

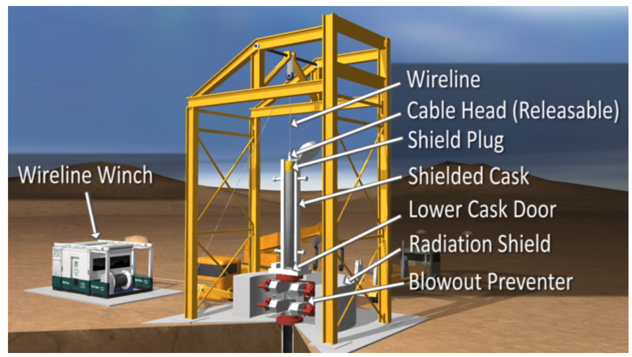

Fig. 4. Depiction of wireline emplacement.

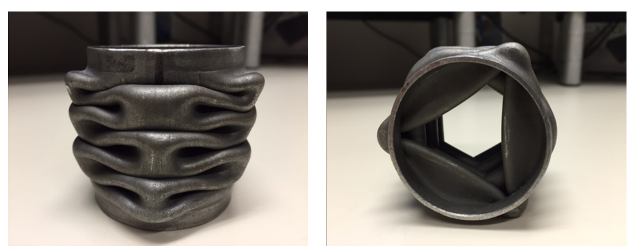

Fig. 5. Tubular crush box impact limiter, after crushing (Ref. 3; photos provided by Brad Day, SNL).

The probabilistic risk assessment included off-normal events, but only those that could occur in conjunction with emplacement operations downhole and at the wellhead. A class of off-normal events that was not considered because it does not readily discriminate between emplacement options, is dropping packages (or casks containing packages) in air at the surface. Evaluation of hazards from such events is currently being undertaken to further evaluate and refine the conceptual design.

II.D. Package Transfer and Wellhead Equipment

The surface handling equipment is intended to safely receive packages from the transportation cask, transfer them to a double-ended transfer cask, position the transfer cask over a disposal borehole, and lower the packages into position at depth. The transfer cask must be double-ended (operable openings at both ends) to lower packages into the borehole. The system is required to serve as part of the pressure envelope for well control, i.e., to contain a hypothetical pressure “kick” during operations as a safety measure. The concept described here meets the engineering challenge of removing or opening a radiation shield at the bottom of the transfer cask and attaching the cask to the wellhead, using components that maintain the pressure envelope capability (e.g., 20 MPa internal pressure).

The transfer cask would have removable shield plugs on both ends, and would receive a WP from the transportation cask in a horizontal position, which is safest (Fig. 6). A side latch mechanism (internal to the transfer cask, not shown) would hold the WP in place until ready for lowering into the borehole. The wellhead configuration would include a rotating shield plate, and equipment operated remotely beneath it, to remove the lower shield plug and attach the transfer cask to a wellhead flange (Fig. 7). Once fixed to the wellhead flange, the transfer cask and associated hardware would become part of the pressure envelope for well control, so that pressure transients encountered during emplacement operations would not necessarily require actuation of a blowout preventer.

Shielding must be provided as a WP is lowered out of the transfer cask into the wellhead. A shield system that allows maintenance of wellhead equipment, or even recovery of a misaligned package, is also desired. The solution is borrowed from a system of sliding and rotating shield plates and removable shield plugs developed for the ORNL Molten Salt Reactor Experiment.

The rotating shield plate above the wellhead would be at grade level (to limit hazards during hoisting) and have a receptacle for the transfer cask in vertical orientation (Fig. 7). The circular plate (perpendicular to the page) would rotate from an initial position over a device for extracting the lower shield plug from the cask, to a second position directly over the borehole. Kneeling jacks (not shown) would lower the cask a few centimeters onto a remotely operated flange on the wellhead. The shield plate would also include tool plugs for access to wellhead equipment below.

The rotating shield plate would support the weight of the transfer cask, which could require a central support post (hidden from view in Fig. 7). A steel thickness of about 12 inches is anticipated for shielding. For the engineering demonstration lighter mockup materials may represent shielding, but the system must support all required loads.

II.E. Transfer Cask to Wellhead Interface

For fluid control purposes, a seal must be established between the central bore of the transfer cask and the guidance casing at the wellhead. This implies a flange connection beneath the rotating shield plate. A remotely-operated clamp such as a Grayloc® flange from Oceaneering International Co., is available in the size needed. The clamp operating mechanism would be permanently attached to the bottom of the transfer cask, and used to secure the lower shield plug to the cask, as well as attaching the cask to the wellhead (Figs. 6 and 7).

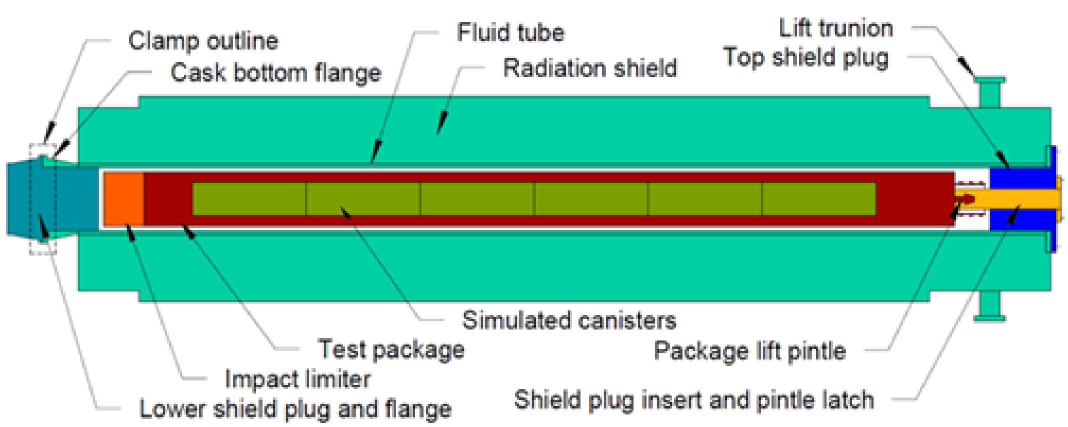

Fig. 6. Transfer cask cross-section, showing a waste package loaded with small canisters that could contain Cs/Sr capsules.

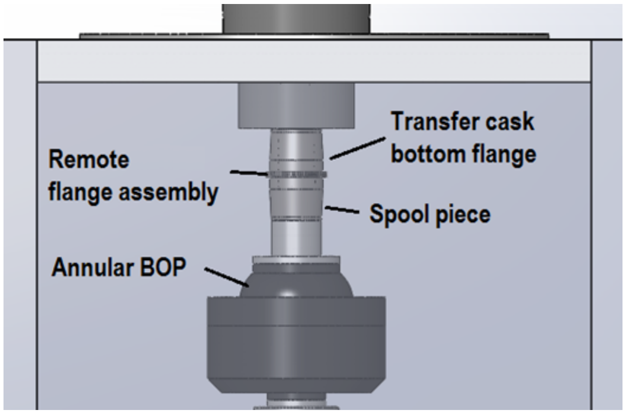

Fig. 7. Transfer cask to wellhead interface.

II.F. Transportation Cask

A legal weight truck (LWT) Type B cask, such as that from NAC International, Inc., was selected as the reference for this conceptual design. Although a double-ended transport cask would be preferred for simplicity of the emplacement concept, no licensed cask large enough was identified.

The cavity length of of the LWT cask is 4.52 m, and the internal cavity diameter is 34 cm which is very close to the inner diameter of the guidance casing (Fig. 1). The cask will not require a certificate of compliance for the DBFT demonstration because no waste will be transported. II.G Transfer Cask to Transportation Cask Interface

II.G. Transportation to Transfer Cask Interface

Packages would be received at the disposal site in the transportation cask and transferred into the double-ended transfer cask prior to being placed over the borehole. This will be accomplished with both casks horizontal in mated cradles using an interface shield. The interface shield will consist of a fixed shield frame and a sliding slab shield (Fig. 8). With the shield in the first position, the transportation cask will be moved into position and the shield plug disconnected and withdrawn into the sliding shield slab. The transfer cask will then be moved into position, and the slab shield moved into its middle position, open to both casks.

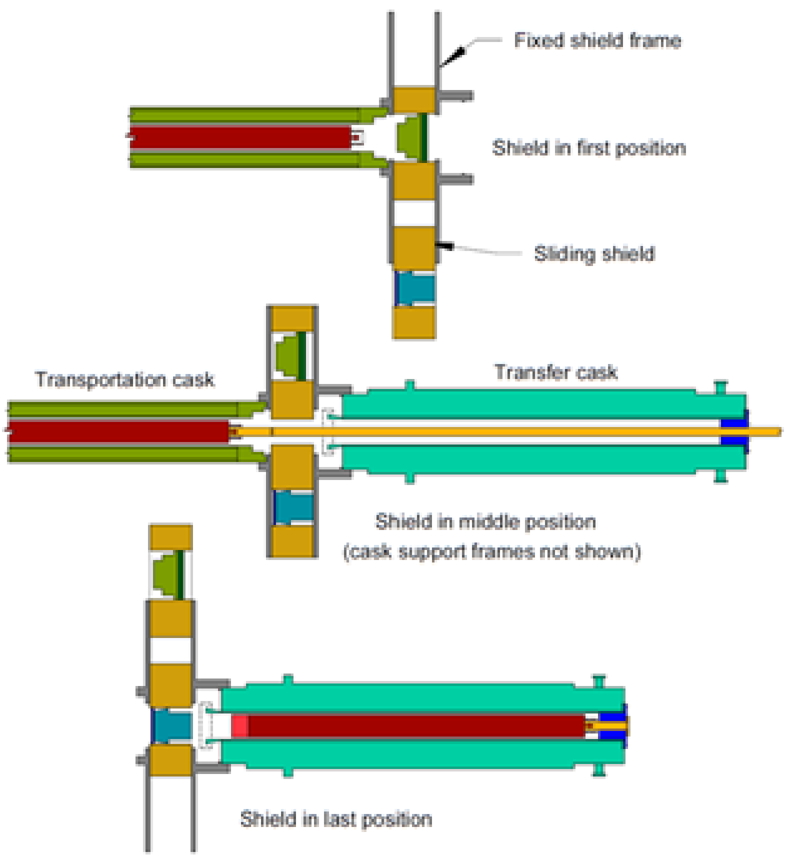

Fig. 8. Operating sequence for the cask interface shield (top view).

The top shield plug on the transfer cask (to the right in Fig. 8) will includes a concentric port with an inner shaft and latch assembly. A shaft extension will be attached, and latched onto the WP. The WP will then be pulled into the transfer cask and the shaft extension is replaced by temporary shield plug.

The shield slab, with the lower transfer cask plug pre-positioned, will then be slid to its last position. With the plug providing shielding for the operators, the empty transportation cask will be moved away and the transfer cask lower shield plug pushed into place. The Grayloc® clamp will be actuated to secure the shield plug, and side-lock pins (not shown) inserted into indents in the package. The transfer cask is now ready to be moved into position over the borehole. A similar process in reverse, would be used to remove a WP retrieved from the borehole.

II.H. Wireline Sealing Components

The tool string that couples the electric wireline to the WP will consist of an electromechanical disconnect, weight sensing and position indicating logs, and a wireline cable head. (Fig. 9). Since the design requirements call for wellbore pressure control, a fluid pressure seal is needed at the top of the cask. A fluid control tube, commonly called a lubricator, will be mounted on top of the cask. The wireline entry into the lubricator will be sealed with a closely-fitted grease tube and stuffing box. The stuffing box will provide a static seal, while the grease tube will be used for running wireline in and out. In the event a WP becomes stuck, modifications to this configuration could allow use of wireline or even drill-pipe deployed fishing tools.

II.I. Emplacement

The assembled placement system, including pit shield, transfer cask, tool string and lubricator, wireline seal, and wireline sheaves is shown in Figs. 10 and 11. 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.

Supporting equipment not shown includes electric power, water supply, borehole fluid management, instrumentation, and a control station. Other site features include pads, a headframe (crane will be used for demonstration), and a decontamination station.

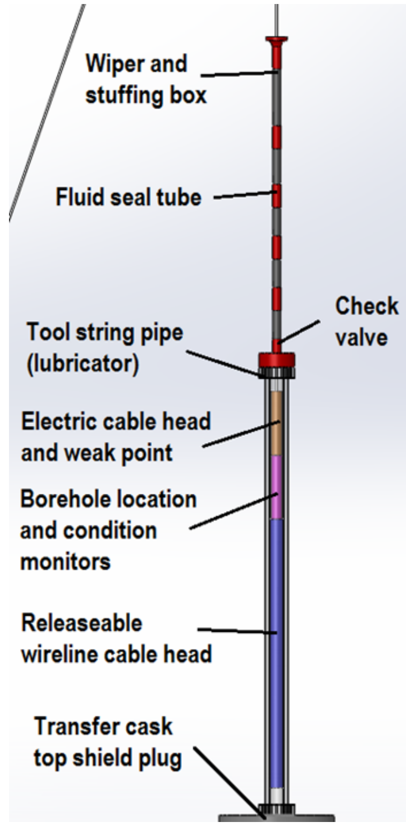

Fig. 9. Reference tool string and fluid seal components.

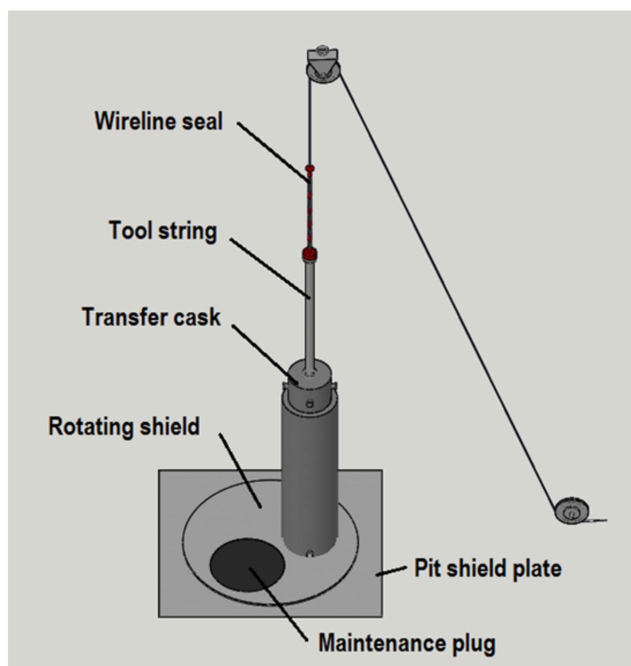

Fig. 10. Schematic of wellhead with transfer cask, and wireline connected ready for lowering the WP.

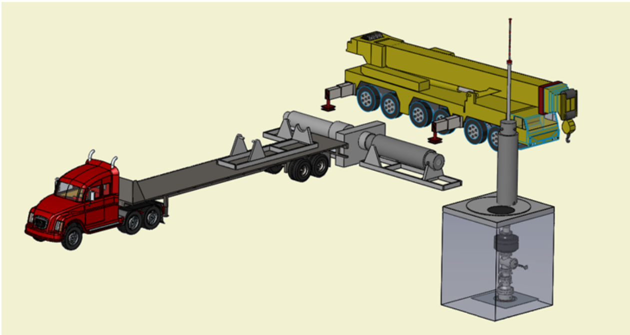

Fig. 11. Layout of cask interface and wellhead, with crane and LWT cask transport vehicle.

III. DEEP BOREHOLE FIELD TEST

III.A. Integrated Test

An integrated test of all components described above, in a controlled environment with on-site shop capabilities, will allow checkout of fit and function, data collection, and safety features prior to deployment at a remote DBFT engineering demonstration borehole site.

A shallow borehole and wellhead mockup will be constructed (Fig. 12), including wellhead components such as the BOP, flanges, and valves as appropriate. The test borehole will be deep enough so that a test package and the entire wireline tool string can be lowered completely through the wellhead. The figure depicts the borehole and the lower plug removal stations; these would actually be 120° apart on the rotating shield plate thereby allowing room for a third maintenance access position. The transfer cask image on the right is for the actual cask; the image on the left depicts a mockup without heavy shielding, but sufficient to demonstrate key interfaces.

A pad will also be provided to demonstrate transfer of test packages from the transportation cask to the transfer cask, and vice versa. Rented equipment, such as the actual wireline system to be used in the field, will be inspected and operated at the test facility prior to mobilization. Demonstration equipment will be moved to the field site immediately on completion of the integrated test.

III.B. Engineering Demonstration at the Field Test Borehole

Demonstration at the FTB will be performed when borehole drilling and characterization, test package fabrication and testing, surface handling and emplacement equipment development, and integrated testing are complete. The site will be graded and gravel or concrete pads will be constructed. The support functions discussed previously will be provided at the site. The wellhead and pit with rotating shield and handling equipment will be constructed and tested before the casks, test packages, and wireline truck are brought on site.

The demonstration will emplace two or more test packages, at least once, with release of the test packages at the bottom of the borehole, and immediate retrieval. A gauge ring and junk basket will be run on wireline prior to test package emplacement, using the lubricator attached directly to the wellhead through the shield plate. An operating sequence will then be followed for package transfer, staging over the borehole, emplacement on the bottom, and release. For retrieval the wireline will be withdrawn through the top shield plug in the transfer cask, and a fishing tool fitted. Package handling steps will be essentially the reverse of emplacement, returning the test package to the transportation cask.

A special instrumented test package will be used to record shock and vibration during emplacement/retrieval. The instrumented package will also be free-dropped (released at the surface, but within the fluid column) to record terminal sinking velocity, impact, and mechanical effects on the way down. This is a key part of the DBFT demonstration, to evaluate the potential for dropping a package to lead to package breach. The resulting data will be used to evaluate the basis for selecting the wireline emplacement method as a safer alternative.

The demonstration may also include testing the performance of various inspection and maintenance activities, and recovery from certain off-normal conditions. These activities have not yet been defined. At the completion of the DBFT engineering demonstration, all test equipment will be removed from the site.

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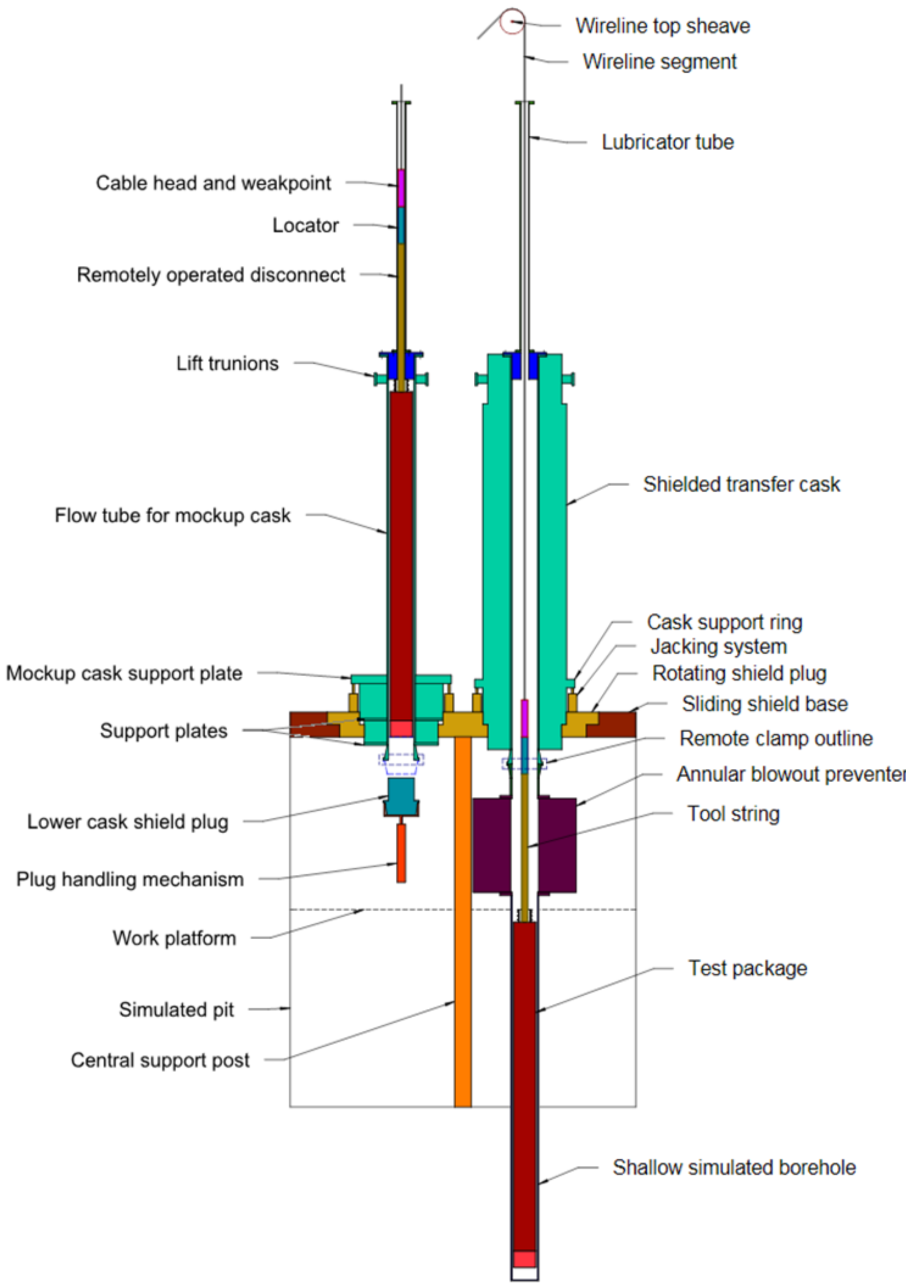

Fig. 12. Schematic of an integrated test of wellhead components, for the engineering demonstration. The shield plug removal station is shown with a mockup test package (left). The borehole station is shown with a fully shielded transfer cask (right).