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Design Verification of Deep Boreholes: A Review of Available Inspection Tools

Robert J. Finch, Heidi A. Smartt, Risa Haddal

Sandia National Laboratories
P.O. Box 5800, MS-1371, Albuquerque, NM, 87185-1371 USA
rfinch@sandia.gov

ABSTRACT

Deep borehole disposal (DBD) has been suggested as an option for disposing spent nuclear fuel in a number of countries, including several countries that are subject to international safeguards. DBD presents some distinct challenges for safeguards compared to a conventional mined geological repository (MGR), including the ability to verify declared design information about the borehole. The ability to verify a borehole's design is crucial for assuring that spent fuel or other accountable nuclear materials are disposed as declared in a borehole of known and verifiable design. This study reviews existing commercial off-the-shelf (COTS) borehole inspection tools currently used by the drilling industry, and evaluates the capabilities of those COTS inspection tools against how well they can meet potential needs and requirements of Design Information Verification (DIV) inspections for international safeguards. The study identified several promising COTS borehole inspection tools that might be used for DIV safeguards inspections and suggests possible modifications and future testing.

INTRODUCTION

Disposal of nuclear and radioactive wastes in deep boreholes (3-5 km) has been examined as a possible alternative to mined geological disposal. Unlike mined repositories, a deep borehole (DBH) is inaccessible to humans and cannot be inspected directly. A recent study of safeguards considerations for deep borehole disposal (DBD) identified challenges to verifying a deep borehole's declared design through safeguards inspections known as design information verification (DIV).[1] These challenges are due in part to the lack of inspection tools available for DIV inspections of DBHs. We review in this report commercial off-the-shelf (COTS) borehole-inspection tools currently used by the drilling industry, and evaluate capabilities of those COTS inspection tools against how they might meet requirements for DIV inspections of DBHs.

Key design features of a DBD facility of interest for DIV inspections include (1) waste-canister design; (2) design, construction and use of surface facilities; (3) design features relevant to a DBD facility's operations and closure, including seals used to close and permanently seal individual boreholes; (4) the layout of borehole arrays (if applicable); and (5) the design and construction of individual boreholes.

Specific borehole design features of interest for DIV include a borehole's depth, trajectory, geometry, and distance from adjacent boreholes, as well as certain casing properties (diameter, material properties) and plans and design criteria for potentially retrieving emplaced waste canisters. DIV tools should be able to detect deviations from declared borehole design, including changes in the above parameters as well as the ability to detect side holes, unexplained gaps in casing and borehole cement, undeclared changes to, or substitutions for, declared casing materials, and any undeclared features that might be hidden behind removable casing or other obstructions.

KEY FINDINGS

A large variety of COTS borehole inspection and logging tools are available, and their use is both extensive and routine in the field. Many commercial uses for these tools apply directly to achieving safeguards-relevant DIV objectives, such as inspecting casing and cement properties, borehole and casing diameters, and borehole trajectory. Other applications relevant to DIV inspections may require specialized testing, modifications, or both. Capabilities relevant to these non-standard safeguards applications mostly involve identifying and locating undeclared design features, including those that might be hidden behind installed casing. For example, inspection tools will be needed that can identify hidden side holes (dog legs) or other design variations such as undeclared high-strength, corrosion-resistant casing or casing with larger-than-specified diameter (potentially hidden behind smaller-diameter, removable casing). The first of these (side holes) could indicate undeclared shallow storage for waste canisters to be recovered later; the latter (variations in declared casing design) are potentially indicative of plans for retrieving waste canisters after emplacement.

Broadly speaking, borehole-inspection tools are used either during drilling (known as measurement while drilling [MWD] and logging while drilling [LWD]) or after drilling has been completed, before or after borehole casing has been fully installed (or both). The drilling contractor (or operator) commonly uses MWD and/or LWD to monitor and evaluate drilling progress, including borehole trajectory, among other objectives. A DIV inspection might be able to use inspection tools employed, or data obtained, by the operator during drilling (with appropriate joint-use protocols and data/signal branching, encryption and authentication, as necessary); however, for we assume that DIV inspections are most likely to be performed on completed boreholes using IAEA-dedicated inspection tools. Nevertheless, shared use of some operator-owned equipment may be unavoidable, most notably hoisting, hauling and wireline equipment for handling and operating borehole-inspection instruments.

Most borehole-inspection tools evaluated for this report are designed to operate in a borehole that contains a fluid, most commonly drilling mud; however, if DIV inspections are restricted to being conducted after each borehole is completed and fully cased, DIV inspections could be limited to using only instruments that can operate in air. For this reason, we emphasize equipment that can operate in air, including some equipment that is designed for use in shallow boreholes (less than 2,000 m) or at temperatures and pressures lower than expected near the bottom of a 5 km-deep borehole. Such equipment would likely need modifications to their designs (or add-on equipment) to make them useful at DBH depths. Nevertheless, depending on drilling technology and other specifics of individual borehole construction, fluids may be present during borehole inspections (or might be added for that purpose), and many fluid-dependent instruments are included here. Indeed, because some information of interest for DIV inspections might only be obtained from these fluid-dependent instruments, conducting DIV inspections in fluid-filled boreholes might be an imperative. Tab le 1 lists COTS tools that might be used to glean information relevant to DIV inspections according to ambient borehole environment (air or fluid) in which these tools can operate.

TABLE 1. Potential DIV inspection tools and applicable borehole environments

Inspection parameter	Air & Clear Water	Drilling Mud
Borehole images	Optical video cameras Optical Televiewers	Acoustic Televiewers
Casing/Borehole Diameter	Multi-finger Calipers	Multi-finger Calipers Acoustic & (most) EM scanners
Casing & Cement properties*	Magnetic flux leakage tools (casing thickness) (some) electromagnetic scanners	MFL ultrasonic cement-bond logging tools
Borehole trajectory	Multi-finger Calipers w/ inclinometer Gyroscopes Magnetometers (w/o casing)	Multi-finger Calipers w/ inclinometer Gyroscopes Magnetometers (w/o casing)

* An evaluation of cement properties (cement-bond logging) might reveal hidden gaps or side holes.

RECOMMENDATIONS

Determine DIV inspection requirements and contingency plans. In order to identify the most appropriate tools for use in a DIV inspection, inspection requirements need to be established. For example, will a survey of the completed borehole with installed casing provide sufficient information for an unambiguous conclusion to be drawn? Will information about a borehole's construction be needed before completion? If so, how is that information to be obtained (e.g., sharing operator equipment during MWD or interrupting drilling operations for independent inspections)? If a question arises from DIV information obtained, what additional information will be needed to draw a firm conclusion? What additional equipment (or different survey methodology) can obtain the necessary information? Answers to questions such as these will help determine which tools are needed to provide necessary information at the appropriate time.

We assume here that DIV inspections are most likely to be performed after a borehole has been completed and the casing installed. The environment considered most likely during a post-completion DIV inspection is an air-filled borehole, severely limiting tools available for in-depth examination of casing and cement properties (potentially making the detection of gaps or side holes more challenging). An operator's drilling plans could impact such an assumption. For example, if a borehole is drilled with the use of drilling mud, a DIV inspection might be performed before the mud is removed, using appropriate acoustic and electromagnetic (EM) scanners; then a final (separate) optical inspection of the borehole might be conducted after mud has been removed.

Use compatible instruments in a single down-hole inspection tool when possible. Because of the time and effort associated with handling borehole inspection equipment (including hauling from on-site storage to a borehole and lowering on a wireline) a single downhole probe with multiple inspection tools is desirable, maximizing information gleaned from a single inspection survey or trip.

For example, if inspecting an air-filled borehole after completion, we recommend a multi-finger caliper (MFC) equipped with optical video camera plus inclinometer. Such a tool would provide visual information about the inner casing while recording casing diameter and inclination. The possibility of including a magnetic flux leakage (MFL) tool with air-capable EM scanner on the same probe would further increase efficiency and provide additional information about casing properties (thickness, gaps and material properties) as well as identifying gaps behind casing. It is unclear from our analysis that such a multi-tool is feasible (this would need confirmation from tool suppliers), but it is not uncommon to deploy more than one instrument in a single wireline trip.

Use operator-owned hauling, hoisting and wireline equipment. COTS tool weights can range from a few tens of kg to more than 100 kg, and tool lengths can reach 5 or 10 m (or more), making the handling of most inspection tools by individuals difficult or impossible, and potentially dangerous. Most COTS inspection tools require special hoisting and hauling equipment; however, such equipment is likely to be available at the drilling site, owned or leased by the drilling operator. Rather than purchasing hoisting and hauling equipment for dedicated use by DIV inspectors, entering an agreement with the operator to share such equipment seems a clear choice, especially as such equipment does not impact measurements. In addition, most inspection tools evaluated by us are deployed downhole on a wireline (or slick line), also likely to be in use on site by the operator. Shared use of wireline that contains telemetry for communications may require special arrangements or modifications for inspection tools using a shared wireline. Where possible, tools that store data in memory downhole for later downloading to a computer at the surface are recommended for DIV inspections.

Combine remote sensing at a DBD facility with DIV inspections of individual boreholes. The ability to detect all possible undeclared design features in a completed borehole is unlikely to be straightforward, even with state-of-the-art inspection tools. Remote sensing of drilling activities during the construction and operation of a DBD facility can provide additional assurance about the absence of undeclared design variations and improve confidence in the ability to detect them. Seismic/acoustic monitoring of drilling activities, in particular, is recommended as a complement to individual borehole inspection.

Consult with borehole inspection-service providers. Many borehole-inspection tools evaluated by us use technologies that require special knowledge and training to operate safely and effectively and to interpret data appropriately. Numerous borehole logging and inspection services are available, and these have expertise and experience with a wide variety of borehole evaluations.[2] We recommend that the inspectorate consult one or more such service providers for advice on tool use and possible for training DIV inspectors.

This recommendation brings us to another possibility, which is to out-source DIV inspections to an independent service provider.

Alternative Option: Use a commercial logging and borehole-inspection service for DIV inspections. Given the number of companies that provide professional borehole logging and inspection services, combined with training, handling and other requirements for proper tool use, it seems prudent to explore the possibility of hiring a well-logging service provider with appropriate experience and expertise to conduct DIV inspections. This may break from existing DIV safeguards practice and would require appropriate arrangements. Nevertheless, if possible to implement, this option could significantly increase confidence in obtaining reliable DIV information with minimal effort, delay or disruption in the field.

Explore novel technologies for DIV inspections of deep boreholes. Despite the range and variety of COTS borehole inspection and logging tools, certain unique demands for DIV inspections may not be fully addressed by current COTS technologies, as some tools might be used to glean information they are not really designed to extract. Applying technologies used for other applications to borehole DIV inspections could prove promising. For example, ground-penetrating radar might effectually detect gaps and side holes in an air-filled borehole, provided such equipment could be integrated into a downhole probe. Another example might be to develop a modified IR (infra-red) range finder to probe borehole diameter or other casing features of interest for DIV inspections. In fact, testing COTS borehole-inspection tools under realistic condition could reveal potential gaps in DIV information.

CONCLUSIONS

Deep borehole disposal of nuclear waste presents several unique challenges for safeguards as compared to waste disposal in a conventional mined geological repository (MGR). These challenges include the ability to verify declared design information about a borehole. The ability to verify a borehole's design is crucial for assuring that spent fuel or other accountable nuclear materials are disposed as declared in a borehole of known and verifiable design. We have reviewed commercial off-the-shelf (COTS) borehole inspection tools currently used by the drilling industry and evaluated the capabilities of those COTS inspection tools against how well they might meet potential needs and requirements of Design Information Verification (DIV) inspections for international safeguards. The study has identified several promising COTS borehole inspection tools that might be used for DIV safeguards inspections and suggests possible modifications and future testing.

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[2] A list of well-logging service companies is available from the Oildex web site (https://www.oildex.com/resources/directory/service-companies/#well-logging); however, the authors of this study made no attempt to assure all information on that site is correct or complete.