Department of Energy
Washington, DC 20585

June 9, 2016

Rodney C. Ewing, Ph.D.
Chairman
U.S. Nuclear Waste Technical Review Board
2300 Clarendon Blvd.
Suite 1300
Arlington, VA 22201

Dear Dr. Ewing:

The Department of Energy (Department) appreciates our meeting with you and staff of the U.S. Nuclear Waste Technical Review Board (the Board) to discuss the recent report, *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program*. The Department has carefully reviewed the report to understand the insights and conclusions.

I'm pleased to report that many of the Board's suggestions have already been included in the plans for the Deep Borehole Field Test (DBFT), a program designed to evaluate the technical and programmatic feasibility of the deep borehole disposal concept. A general response to the Board's report is presented in the context of the DBFT as Enclosure 1. The Board's report identified four findings and made nine specific recommendations; our detailed responses to these are included in Enclosure 2. I should note that we find the report potentially misleading and open to interpretation regarding our plans for the DBFT. I should also note that while many of the experts expressed their opinions regarding borehole disposal at the workshop, few made the clear distinction between what was appropriate for the DBFT (which does not involve radioactive waste) and an actual waste disposal facility based on the borehole concept. We are incorporating into our plans the Board recommendations that are consistent with both the research focus of the DBFT and DOE's budget and schedule considerations that constrain the DBFT.

The Department recognizes that there is much work to do to bring about disposal of high-level radioactive waste and spent nuclear fuel, and we acknowledge the Board's many contributions in helping us to evaluate various disposal concepts, including the deep borehole. If you have any question about our responses, please contact Andrew Griffith at (202) 586-3715.

Respectfully,

John F. Kotek
Acting Assistant Secretary
for Nuclear Energy

Enclosures

Enclosure 1

DOE's Summarized Response to the NWTRB Report on the DOE Deep Borehole Disposal Research and Development Program

The overall objective of the Deep Borehole Field Test (DBFT) is to demonstrate and evaluate technologies necessary for determining the feasibility and safety of deep borehole disposal for practical and safe disposal of smaller DOE-managed waste forms. In October 2015, at the Nuclear Waste Technical Review Board (NWTRB) International Technical Workshop on Deep Borehole Disposal of Radioactive Waste, and in prior DOE reports and presentations, DOE described planned DBFT activities to achieve this overall objective (see the References section at the end of this summary). These activities are for the most part consistent with those recommended by the NWTRB in their recent report, *Technical Evaluation of the U.S. Department of Energy Deep Borehole Disposal Research and Development Program*, January 2016. The DBFT is not intended to characterize a specific location as a potential disposal site. DOE will limit the scope of its research and demonstration activities and DBFT data collection to what is needed to evaluate the technical feasibility of the deep borehole disposal concept.

The DBFT scope is focused on achieving the following field test objectives (MacKinnon, 2015 and Sassani and Hardin, 2015):

1. Obtain a suitable test site
2. Design, drill and construct the Characterization Borehole (CB) to requirements
3. Collect data in the CB on geological, geomechanical, geochemical, and hydrologic conditions in the crystalline basement
4. Design, drill and construct the Field Test Borehole (FTB) to requirements
5. Design, develop, and demonstrate surface handling and emplacement equipment systems, test packages, and operational methods for safe canister/ package handling and emplacement with analyses of associated risks
6. Conduct generic post-closure safety analyses, utilizing DBFT data sets
7. Evaluate the feasibility and safety of the deep borehole disposal concept for disposal of smaller DOE-managed waste forms

These objectives will be accomplished by a DBFT team of recognized US and international experts with extensive experience in drilling, down-hole operations and testing, site characterization, safety assessment, and project management. This team includes the DBFT Contractor Team (Battelle Memorial Institute, Schlumberger, Solexperts AG), DOE, and technical experts from DOE National Laboratories (SNL, LANL, LBNL, ORNL, PNNL). A Technical Advisory Committee (TAC) will be established to monitor field test activities, especially during drilling and testing, and ensure the necessary data and information is collected. The membership of the TAC shall include key members of the DBFT team, and/or other external experts as necessary. *DOE does not believe, as recommended by the NWTRB, that it is necessary to have an additional group of experts review the drilling program design and implementation, nor is it necessary for an independent group to report on the field test to the Secretary of Energy.*

Descriptions of how each of these objectives will be accomplished are summarized below. Contrasts between the DBFT and actual disposal activities are included in the following

summary along with remarks (noted in italics) related to recommendations made by the NWTRB.

Field Test Objective 1: Obtain a suitable test site

A number of geological, hydrogeological, and geophysical characteristics have been evaluated that are relevant to successfully completing the DBFT, and are derived from those delineated for post-closure safety for a deep borehole disposal system. This evaluation has produced guidelines for selecting a suitable site based on existing geologic information (see Arnold et al., 2014 and Sassani and Perry, 2015). These guidelines were developed with the primary goal of identifying potential favorable sites that appear to have a crystalline basement geology relatively isolated from the associated subsurface hydrogeologic system and biosphere. DBFT site selection will be based on existing geologic information and an evaluation of how well the site meets the guidelines. *In addition, DOE has concluded that for the specific purposes of the DBFT, the likely value of information gained at depths of 3-5 km from surface-based techniques does not warrant the expense of surface-based geophysical investigations at the scale the NWTRB envisions or recommends.* The need for and use of geophysical investigations in the context of the DBFT and deep borehole disposal are discussed further in the following paragraph.

Note that the DBFT has the objective of specifically addressing key data necessary to evaluate the feasibility of the deep borehole disposal concept, particularly unproven or especially critical components (e.g., collecting diagnostic geochemical and environmental tracer profiles from deep low-permeability crystalline rocks – See Field Test Objective 3), but does not address broader objectives that would be required for site characterization supporting actual implementation of a deep borehole disposal facility. For example, selection of a site suitable for an actual disposal facility would potentially involve site characterization investigations prior to drilling (e.g., surface-based and/or airborne geophysical surveys), but a decision to conduct such investigations would depend on the geologic information already available (e.g., indications of through-going faults or fracture zones), on the disposal safety case for that site, and on the needs of particular stakeholders.

To summarize, the DBFT will include sampling and testing of formations in the crystalline basement to detect and characterize discontinuities that intersect the borehole if they are present. However, surface-based geophysics, multi-borehole studies, and extensive downhole testing to characterize larger-scale, distal discontinuities that may be present, are not planned. If data from the crystalline basement hydrogeologic system (see Field Test Objective 3) indicate that it has direct/active connection to shallow meteoric groundwater aquifers and/or the biosphere, then additional activities could focus on identifying the transport pathway. For a potential disposal site, identification and characterization of potentially significant transport pathways could be carried out using conventional approaches such as: additional boreholes; surface, downhole, and cross-hole geophysical techniques; and borehole tracer and pressure tests. *DOE does not currently plan to use the characterization and field test boreholes to conduct cross-hole monitoring to provide information on the characteristics of the rock volume surrounding the boreholes*. However, if the deep borehole disposal concept is determined to be feasible, DOE may choose to conduct such a study in the future.

Field Test Objective 2: Design, drill and construct the Characterization Borehole to requirements

This objective is to demonstrate, using existing technology, that a borehole having a bottom-hole diameter of 8.5 inches, with a specified maximum deviation, can be drilled to a depth of 5 km (with the last ~ 3 km in the basement), cased, and cemented to requirements. A preliminary design for the CB has been developed and documented (Kuhlman et al., 2015). Kuhlman et al. (2015) focuses on the conceptual design requirements of the DBFT, specifically the construction and completion of the CB and the FTB, as well as the characterization activities to be performed in the CB. The final design for the drilling and construction of the CB is being developed by a team including Battelle Memorial Institute, Schlumberger, Solexperts AG, DOE, and National Laboratory personnel and will be described in detail in the final Drilling and Test Plan (D&TP).

Field Test Objective 3: Collect data in the Characterization Borehole on geological, geomechanical, geochemical, and hydrologic conditions in the crystalline basement

The primary focus of this objective is to identify and evaluate key characteristics of the basement that are important to the safety of the concept and long-term waste isolation (MacKinnon, 2015 and Sassani and Hardin, 2015). *This objective is consistent with the NWTRB recommendation that the project team carefully consider the key parameters for the safety case that need to be measured during sampling and testing in the 2- to 5-km (1.2- to 3.1-mi) depth range encompassing the seal and disposal zones.* These characteristics include: ancient age of formation fluids that would indicate a system that has been isolated hydrologically from the biosphere (i.e., local, rock-dominated conditions) for millions of years; geochemically reducing conditions in the rock-brine system that would substantially inhibit mobilization of many important radionuclides; increasing brine density with depth that would act counter to any thermally-driven buoyancy flow that may enhance transport of radionuclides to the biosphere during the short-lived thermal period; and very low basement rock permeability. These key characteristics have been observed in previous studies of crystalline basement formations in the US, Canada, and Europe and are expected to exist at the suitable DBFT site. Data will be collected to evaluate:

- Deep groundwater in the crystalline basement to assess if it is very old, saline, dominated by rock reactions (i.e., rock equilibrated), and reduced/reducing;
- Formation fluid pressure, to check whether an ambient fluid potential gradient exists to drive flow from the deep disposal zone to the shallow subsurface (i.e., over-pressured conditions present at depth), or conversely, if under-pressured conditions exist in the crystalline basement hydrology (which would be favorable for isolation);
- Bulk permeability properties of the host rock and of the borehole disturbed rock zone (DRZ), if one exists, to assess disturbed transport properties (i.e., permeability at the borehole scale, rather than the core scale); and
- Uncertainty and variability in data, to assess data transferability and to support site-specific numerical models of waste isolation performance (i.e., geochemical, thermal, geomechanical, geohydrological properties and constitutive laws) and post-closure safety.

The types of data and the technologies needed to collect them (as the borehole is being drilled and after borehole completion) have been identified and described by Kuhlman et al. (2015). The

types of data to be collected as a function of depth will focus on providing data *for key parameters for the safety case* and include:

- Crystalline basement faults and fractures near the borehole
- Lithology and stratigraphy
- Physical and transport parameters
- Geochemical parameters
    - Fluid composition
    - Stable isotope ratios (e.g., ^{2}H, ^{18}O)
    - Uranium decay series isotope ratios
    - Strontium isotope ratios
- Geomechanical parameters
- Environmental tracer transport parameters

The subsurface geology and variable in situ conditions at depth will be developed from existing data and from new characterization data from the DBFT, and will be organized and synthesized in the form of a three-dimensional site geologic framework model. This model will include heterogeneity and variability in geologic properties consistent with the collected and available information and will provide data transparency and facilitate data access. Key geologic inputs for the geologic framework model include the stratigraphy and any known structures of the selected area, with a focus on the depth to the crystalline basement, mineralogy and rock fabric/texture, identified aquifers and permeable zones, stress regime, physical rock properties, and the scale of heterogeneity within rock units. *The data will be used to provide key inputs for post-closure safety assessment modeling efforts and to address technical and scientific issues related to the potential heterogeneity of the subsurface geology and complex in situ conditions a depth.*

As summarized above, the focus of DOE's field test will be to collect data and conduct analyses that are in large part consistent with that recommended by the NWTRB. However, again it is emphasized that DOE will limit the scope of its DBFT data collection to that needed to evaluate the feasibility of the deep borehole disposal concept, which is a lesser scope than would be needed to fully characterize a disposal site.

Field Test Objective 4: Design, drill and construct the Field Test Borehole to requirements

The primary goal of this objective is to evaluate whether, using existing technology, a borehole having a bottom-hole diameter of 17 inches, with specified maximum deviation and dogleg severity, can be drilled to a depth of 5 km (with the last ~ 3 km in the basement), and completed to requirements that allow safe emplacement of surrogate waste packages to depths between 3 and 5 km. A preliminary design for the FTB has been developed and documented (Kuhlman et al., 2015). The process for developing the final design and the drilling and test plan (D&TP) for the FTB will use experts from contractors, National Laboratories, and DOE similar to that described above for the CB.

Limited subsurface characterization is planned for the FTB, and planned characterization will focus on evaluating the quality of the FTB construction. Note that in an actual disposal facility some downhole characterization might be included depending on the distance from other boreholes, and geologic characteristics of the site. *In addition, DOE does not currently plan to conduct on-going subsurface monitoring in the FTB after emplacement testing, as was*

recommended by the NWTRB, primarily because of the limited value of information that could be collected within the time frame of the DBFT as currently planned. However, if the deep borehole disposal concept is determined to be feasible and the FTB is not closed at the end of the DBFT, DOE may choose to conduct a monitoring study in the future.

Field Test Objective 5: Design, develop, and demonstrate surface handling and emplacement equipment systems, test packages, and operational methods for safe canister/package handling and emplacement with analyses of associated risks

The scope of this objective is to design, build, and operate a system that represents what could be used for an actual disposal system and radiological operations involving radioactive waste. The extent of this system and the field test is limited to evaluating and demonstrating system elements and safe handling operations that are unique to deep borehole disposal, such those involving the interface between cask unloading, borehole emplacement of test packages, and retrieval of test packages. Wireline emplacement of test packages will be demonstrated in the field test. This mode of emplacement was selected based on the evaluation of cost and risk described in SNL (2015). An evaluation of this work is documented in a report by AREVA (2016). DOE will develop a description of the handling operations and system elements that will be utilized in the DBFT prior to implementation. *Risk analyses will be conducted for handling and emplacement operations and important potential accident scenarios, but these analyses will be limited to operations unique to deep borehole disposal and wireline emplacement. DOE does not plan to conduct a comprehensive assessment of other modes of emplacement as recommended by the NWTRB but may consider doing such assessments in the future if the concept of deep borehole disposal is determined to be feasible.* Safe handling of nuclear materials under a variety of handling and transportation conditions is a well-developed discipline and DOE and its interdisciplinary team have high confidence that safe engineering solutions for a complete transportation, surface handling, and emplacement system can be developed if the deep borehole disposal concept is determined to be feasible and DOE decides to pursue disposal of DOE-managed waste forms in deep boreholes. DOE does plan to develop a description of upstream system components and operations for smaller DOE-managed waste forms (Price et al., 2015).

To support the design of a seal system for potential future disposal boreholes, the DBFT will include laboratory studies to evaluate sealing materials at representative temperature, pressure, salinity, and geochemical conditions. *The current field test plan does not include field testing of borehole seals or sealing methods as recommended by the NWTRB. However, DOE will consider such testing if it is determined that field testing is required to complete the evaluation of feasibility. This determination and the design of field testing will require data and analysis and therefore borehole sealing materials and emplacement configurations will be examined in parallel with DBFT field operations, starting from the reference seal design in Arnold et al. (2011) and Hardin (2015).*

Key components of the DBFT seals effort will include:

- Review of borehole seal practices in other borehole-related disciplines such as CO2 sequestration, deep well injection of hazardous wastes, and oil and gas production
- Development of sealing requirements and seal emplacement methods
- Experimental analysis of bentonite alteration and steel corrosion under borehole conditions

- Evaluation of seal-DRZ interface properties for conventional sealing materials
- Consideration of new sealing approaches including novel cements and thermite plugs
- Laboratory verification of rock weld properties

Eventually, the DBFT boreholes may be made available to the scientific and engineering R&D community as a deep borehole underground laboratory. *If the deep borehole disposal concept is determined to be feasible, in situ tests of seal emplacement and performance can be conducted when planned DBFT activities have concluded.*

Field Test Objective 6: Conduct post-closure safety analyses

The post-closure safety case for deep borehole disposal relies primarily on the long-term isolation of the deep geologic environment of the crystalline basement. A key element of the safety case is the demonstration that deep groundwater is very old and has been isolated from the surface or near-surface for very long periods of time (on the order of 10^6 years or longer). The DBFT will evaluate deep groundwater age from geochemical indicators such as salinity, and from isotopic indicators using environmental tracers such as noble gases. High salinity at depth also indicates old groundwater and precludes use of deep groundwater as a drinking water source. Increasing salinity with depth promotes stable stratification based on fluid density, and tends to oppose upward thermal convection from waste heat. Absence of over-pressured conditions at depth is expected at favorable locations for deep borehole disposal. The bulk permeability of deep crystalline rocks is generally very low and decreases with depth. The effectiveness and durability of borehole seals through the period of upward thermal convection are also elements of the safety case and are addressed through a borehole disposal concept that includes multiple barrier seal materials in the borehole above the waste disposal zone. *The post-closure safety case does not rely on waste form and waste package performance because of the isolation capabilities of the deep geologic environment of the crystalline basement.*

Post-closure safety of the deep borehole disposal concept will be evaluated with a comprehensive three-dimensional probabilistic post-closure safety assessment model using the geologic framework model and characterization data developed under Field Test Objective 3. A Features, Event, and Process (FEP) screening approach (Freeze, 2015) will be conducted to determine those FEPs that will be included in the safety assessment model. *DOE does plan to adequately assess coupled processes and the impact of drilling on the natural geologic system, and this FEPs screening process will include evaluation of coupled processes, system heterogeneities, and the impact of drilling on the natural geologic system.* A suite of safety analyses will be conducted to evaluate the long-term performance of a hypothetical deep borehole disposal facility having a geologic system consistent with the DBFT site. Smaller DOE-managed waste forms will be considered as candidate waste forms for disposal. *Alternative scenarios will be considered for accidents such as stuck and abandoned waste packages and geologic conditions that include possible enhanced/additional transport pathways in crystalline basement discontinuities such as fractures and faults. In addition, , if the deep borehole disposal concept is found to be feasible the DOE may evaluate the potential safety benefits of robust waste forms and waste packages in its suite of planned safety analyses.*

Field Test Objective 7: Evaluate the feasibility and safety of the deep borehole disposal concept

This objective will be achieved by synthesizing field test activities, test results, and safety analyses into a comprehensive evaluation of concept feasibility. Data and experience that will be evaluated include data gathered during site characterization, experience gathered during drilling and borehole construction, data gathered during physical demonstration of surface handling and borehole emplacement and retrieval operations, pre-closure safety analyses, and post-closure safety analyses.

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Enclosure 2

DOE Responses to the NWTRB's Specific Findings and Recommendations

Findings

Even if disposal of some radioactive waste in deep boreholes is determined to be feasible, the need for a mined, geologic repository is not eliminated.

The Board's finding supports DOE's position that a mined geologic repository will be required even if deep borehole disposal is implemented. (No additional action)

Establishing a regulatory framework, identifying an acceptable site, and characterizing a deep borehole at depths down to 5 km (3.1 mi) are challenging and time consuming activities, suggesting that the time required for completing a deep borehole disposal facility might be comparable to that of a mined, geologic repository.

The Board's finding identifies some of the unknown factors regarding the deep borehole concept, including schedule uncertainty. The DBFT is limited to analyzing technical feasibility of the concept. (No additional action)

The Deep Borehole Field Test will provide only limited information on which to base an evaluation of the feasibility of the deep borehole disposal concept and the selection of a deep borehole disposal site.

The Deep Borehole Field Test (DBFT) is not intended to collect data to consider a specific site for disposal of radioactive waste. The DBFT should provide significant information to evaluate the engineering feasibility of the disposal concept and aspects of operational and post closure safety. The Department believes this information will inform a site selection process in much the same way the proven deep geologic repository concept informs the site selection process.

The operational implications and limitations of handling and emplacing highly radioactive waste at depth are very different from those for operations involving non-radioactive material; however, evaluating and understanding those implications and limitations are of utmost importance for the design of a deep borehole disposal facility and for the feasibility assessment of the deep borehole disposal concept.

The second phase of the DBFT will demonstrate surface handling and downhole emplacement of surrogate waste packages in the full-diameter field test borehole. This demonstration will be representative of actual operations needed for radioactive waste disposal. (No additional action)

Recommendations

Independent expert review—The Board recommends that DOE ensure the drilling program design and implementation are reviewed by experts with extensive experience in drilling and down-hole operations (e.g., logging, testing, well completion) and in designing and operating equipment for handling highly radioactive material. These experts should be independent of the Deep Borehole Field Test contractor and of the lead national laboratory on the project, and should be able to monitor the progress of the project and report on it to the Secretary of Energy.

DOE's interdisciplinary team of contractors and national laboratories that will plan and conduct the field test are leading experts in project management, drilling subsurface characterization and testing, nuclear materials handling, and risk and safety assessment. The DOE team is fully capable of presenting to the DOE Secretary, independent experts, review committees, and stakeholders the status and findings of the deep borehole field test as it progresses through its planning and implementation.

A Technical Advisory Committee (TAC) will be established to monitor field test activities, especially during drilling and testing, and ensure the necessary data and information is collected. The membership of the TAC shall include key members of the DBFT team, and/or other external experts as necessary. DOE does not believe, as recommended by the NWTRB, that it is necessary to have an additional group of experts review the drilling program design and implementation, nor is it necessary for an independent group to report on the field test to the Secretary of Energy. (No additional action)

Comprehensive risk analysis—The Board recommends that a more comprehensive risk analysis be completed for all aspects of the drilling and emplacement program as part of assessing the feasibility of deep borehole disposal of radioactive waste. In particular, an analysis should be conducted of what options will be available in the event of an accident during waste emplacement and the implications of such an accident for the safety of recovery operations and the isolation of waste. A transparent and comprehensive assessment of the five possible emplacement modes for deep borehole disposal, including their absolute and relative risks for having and recovering from an accident, also should be completed.

The Department plans to conduct risk analyses for handling and emplacement operations and important potential accident scenarios, but these analyses will be limited to handling operations unique to deep borehole disposal and wireline emplacement. The Department does not plan to conduct a comprehensive assessment of all other modes of emplacement as recommended by the NWTRB, but may consider doing such assessments in the future if the concept of deep borehole disposal is determined to be feasible. (No additional action)

Heterogeneity of subsurface geology and transferability of data and results of analysis—The Board recommends that DOE strengthen its assessment of the feasibility of the deep borehole disposal option by addressing the technical and scientific issues related to the

potential heterogeneity of the subsurface geology and the complex *in situ* conditions at depth. DOE should take into consideration the potential implications, with a focus on conducting a defensible safety analysis and demonstrating the transferability of the data and results of analysis to other sites. DOE should address these issues in the guidance it provides to the contractor for developing the drilling and test plan. Specifically, the project team should carefully consider the key parameters for the safety case that need to be measured during sampling and testing in the 2- to 5-km (1.2- to 3.1-mi) depth range encompassing the seal and disposal zones. For example, DOE should identify down-hole logs, tests, and monitoring techniques that could lead to a better understanding for the potential development of a free gas phase (*e.g.*, hydrogen from the rapid corrosion of steel components) and its implications for disposal system behavior. The goal for characterization should be obtaining relatively continuous down-hole profiles based on multiple measurements, rather than relying on, and interpolating between, a limited set of measurements. DOE also should consider using the characterization and field test boreholes to conduct cross-hole monitoring to provide information on the characteristics of the rock volume surrounding the boreholes. Moreover, on-going subsurface monitoring after the emplacement testing, to continue to test and evaluate starting assumptions, should be included in the drilling and test plan.

> The Department agrees with the Board that these are topics that need to be considered in developing the drilling and test plan (D&TP); the DOE also agrees with the Board's observation that subsurface geology is heterogeneous and site-specific geologic information obtained during the DBFT will have limited transferability to other locations. Future disposal boreholes, if any, will need individual characterization. The Department believes that the DBFT will provide valuable information about the feasibility of the disposal concept in a generic sense in multiple ways: e.g., by informing preliminary site screening criteria, by demonstrating construction of boreholes to requirements, by providing the opportunity to evaluate down-hole characterization techniques, and by providing a test of operational engineering techniques. (No additional action)

Pre-drilling geophysical subsurface characterization—The Board recommends that the Deep Borehole Field Test include surface-based geophysical surveys to delineate subsurface structure and physical conditions prior to drilling (*e.g.*, detailed gravity, magnetic, seismic, or electrical data). These measurements could help in the design of the Deep Borehole Field Test drilling and test plan and provide knowledge for using surface-based measurements to evaluate the subsurface characteristics of potential deep borehole sites prior to drilling.

> The Department appreciates the Board's suggestion for surface-based geophysical characterization prior to drilling, and intends to use available information. However, the Department has concluded that for the specific purposes of the DBFT, the value of information gained at depths of 3-5 km from surface-based techniques is unlikely to warrant the expense of surface-based geophysical investigations at the scale the Board envisions. (No action)

Robust waste forms, waste packages, and seals—The Board recommends that DOE explicitly analyze the potential safety benefits of using more robust waste forms and waste packages as part of assessing the feasibility of the deep borehole disposal concept and in developing the associated safety case. The Board also recommends that the Deep Borehole

Field Test be used to demonstrate emplacement of potential seals and to test the efficacy of seal materials in dealing with breakouts and evolving damage zones around the borehole when exposed to *in situ* thermal, hydrogeologic, geomechanical, microbiological, and chemical conditions. Geophysical techniques (*e.g.*, acoustic sonic and ultrasonic tools) should be used to verify the seals between the casing and rock where the casing remains in the borehole.

> If deep borehole disposal is found to be feasible, the DOE may evaluate the potential safety benefits of robust waste forms and waste packages in follow-on studies. DOE does plan to investigate the behavior of different seal materials in the laboratory under representative downhole temperature, pressure, and chemical conditions to inform our effort to design a seal system. This information will be used to evaluate opportunities for in-situ testing of sealing technologies during the course of the DBFT, however, sealing experiments are generally incompatible with future non-nuclear R&D uses of the hole. (No additional action)

Developing an operational safety strategy—The Board recommends that DOE develop an operational safety strategy for the Deep Borehole Field Test that integrates conventional borehole operations and remote handling of highly radioactive materials. This might include emphasizing the use of engineering controls (*e.g.*, automated equipment to protect workers) over administrative controls (*i.e.*, processes that rely on personnel actions and procedures). The Deep Borehole Field Test should simulate implementation of deep borehole disposal as if radioactive wastes were being emplaced in order to test the features of an operational safety strategy that can be applied to a future borehole disposal site and to provide the basis for ensuring safe operations, limiting exposure of workers to hazards or release of radioactive material to the environment, and mitigating waste emplacement risks.

> The Department plan incorporates the Board's recommendation. The Department plans to design, build, and operate a system that represents what could be used for an actual disposal system and radiological operations involving radioactive waste. This system and operations will be demonstrated at the 2nd field test borehole (FTB). Demonstration activities will be limited to evaluating and demonstrating system elements and safe handling operations that are unique to deep borehole disposal, such those involving the interface between cask unloading, borehole emplacement of surrogate test packages, and retrieval of test packages. (No additional action)

Engaging regulators to define retrievability requirements—The Board recommends that, as part of its assessment of the feasibility of deep borehole disposal of radioactive waste, DOE place a high priority on engaging regulators to define retrievability requirements in the context of deep borehole disposal of radioactive waste. DOE should begin defining and clarifying the types of technical information that may be needed to address regulatory issues and then collect that information to the extent practicable as part of the Deep Borehole Field Test.

The Department agrees that regulatory clarity is necessary before any decisions can be made regarding deep borehole disposal of radioactive wastes and will incorporate interactions with the regulators into the project schedule as appropriate. (Pending)

A transparent pathway from the Deep Borehole Field Test to siting—The Board recommends that DOE use the Deep Borehole Field Test to gain experience related to its siting approach. DOE should begin to incorporate new standards of transparency and data access, and should explore avenues to engage stakeholders.

The Department has initiated a process to obtain public feedback to help design a consent-based process. The process will be used to site future nuclear waste facilities - which could include a deep borehole. The consent-based process will be transparent, phased and adaptive. (No additional action)

Chief scientist in charge of the Deep Borehole Field Test program—The Board recommends that the DOE Deep Borehole Field Test program have a chief scientist responsible for integrating the engineering activities (i.e., drilling the characterization and field test boreholes, emplacing and retrieving the simulated waste) and the site characterization activities. The chief scientist should have the scientific understanding required to ensure the technical integrity of information gathered in the Deep Borehole Field Test and its use for developing the safety case for deep borehole disposal of radioactive waste.

In lieu of a chief scientist as envisioned by the Board, the Department will establish a Technical Advisory Committee (TAC) to monitor field test activities. The membership of the TAC includes members of the DBFT Contractor team (Battelle Memorial Institute, Schlumberger, Solexperts AG), DOE, technical experts from DOE National Laboratories (Sandia National Laboratories, Los Alamos National Laboratory, Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory, Pacific Northwest National Laboratory), and/or other external experts as necessary. (No additional action)