SAND2014-20111C

SITING GUIDELINES FOR A DEEP BOREHOLE DISPOSAL FACILITY

Geoff A. Freeze[1], Bill W. Arnold[1], Patrick V. Brady[1], David C. Sassani[1], and Kristopher L. Kuhlman[1]

[1]*Sandia National Laboratories, Albuquerque, New Mexico, USA 87185; gafreez@sandia.gov*

This paper describes considerations for siting a facility for deep borehole disposal of radioactive waste, which include technical, logistical, and sociopolitical factors. Technical factors include geological, hydro-geochemical, and geophysical characteristics that are related to the suitability of the site for drilling and borehole construction, waste emplacement activities, waste isolation, and long-term safety of the deep borehole disposal system. Logistical factors to be considered during site selection include: the local or regional availability of drilling contractors (equipment, services, and materials) capable of drilling a large-diameter hole to 5 km depth; the legal and regulatory requirements associated with drilling, construction of surface facilities, and waste handling and emplacement; and access to transportation systems. Social and political factors related to site selection include the support or opposition of local and state entities and other stakeholders to the facility and its operations.

These considerations are examined in the context of the consent-based siting of a deep borehole field test, designed to evaluate the feasibility of siting and operating a deep borehole disposal facility.

I. INTRODUCTION

Deep borehole disposal for the geologic isolation of spent nuclear fuel (SNF) and/or high-level radioactive waste (HLW) has been considered for many years[1,2,3,4], beginning with evaluations by the US National Academy of Sciences in 1957[5].

More recently, the U.S. Department of Energy (DOE) Used Nuclear Fuel Disposition Campaign (UFDC) has conducted research on generic deep geologic disposal options, including deep borehole disposal in crystalline basement rock[6,7,8,9].

The deep borehole disposal design concept consists of drilling a large-diameter (up to 43 cm [17 in]) borehole (or array of boreholes) into crystalline basement rock to a depth of about 5,000 m, emplacing waste canisters in the lower (~2,000 m) disposal zone portion of the borehole, and sealing and plugging the upper portion of the borehole with a combination of bentonite, cement, and cement/crushed rock backfill. This design concept is expected to be achievable in crystalline rocks with currently available commercial drilling technology.

A generalized deep borehole disposal concept is illustrated in Figure 1, showing that waste in a deep borehole disposal system is several times deeper than typical mined repositories. The typical maximum depth of fresh groundwater resources is also shown in Figure 1, as indicated by the dashed blue line. Safety of the deep borehole disposal concept relies primarily on the great depth of burial, the isolation provided by the deep natural geological environment, and the integrity of the borehole seals.

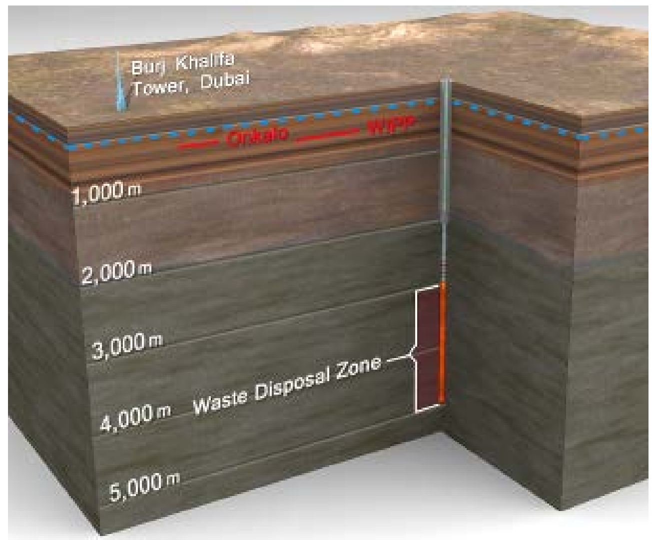

Figure 1. Generalized schematic of the deep borehole disposal concept.

Numerous factors suggest deep borehole disposal of SNF and HLW is viable and safe. Several lines of evidence indicate that groundwater at depths of several kilometers in crystalline basement rocks has long residence times, low velocity, and high salinity. Density-stratified high-salinity fluids have limited potential for vertical flow and colloidal transport of radionuclides. Geochemically reducing conditions in the deep subsurface stabilize low solubility phases and enhance the retardation of key radionuclides.

In 2012, the Blue Ribbon Commission on America's Nuclear Future (BRC)[10] reviewed the prior research on deep borehole disposal, concluded that the concept may hold promise, and recommended further research, development, and demonstration to fully assess its potential. The BRC also recommended a consent-based approach to siting future nuclear waste management facilities. In 2013, consistent with BRC recommendations, the DOE[11] identified as key strategy objectives (i) developing a research and development plan for deep borehole disposal, and (ii) initiating a consent-based siting process.

In accordance with the BRC recommendations and DOE strategy objectives, UFDC has planned a deep borehole field test (DBFT)[12], without actual radioactive waste, to assess the viability of deep borehole disposal concept. The DBFT[12] includes consent-based site selection, site characterization, borehole and field test design, demonstration emplacement of canisters, and an assessment of viability of the concept. As a first step in the DBFT, DOE has issued a Request for Information (RFI)[13] to "seek interest in, and input from, States, local communities, individuals, private groups, academia, or any other stakeholders willing to host a Deep Borehole Field Test."

The remainder of this paper describes considerations for siting a facility for deep borehole disposal of SNF and/or HLW. These considerations are examined in the context of the consent-based siting process for the DBFT. The siting process for the DBFT may be less complex than for an actual disposal facility, but it offers insights into consent-based siting that will be relevant to an actual facility. Also, many of the siting guidelines for the DBFT anticipate the needs for siting and operating a deep borehole disposal facility.

Section II provides an overview of consent-based siting. Section III presents siting considerations for a deep borehole disposal facility. Section IV outlines specific siting guidelines, based on the siting considerations. Section V provides a summary.

II. CONSENT-BASED SITING

Siting of storage or disposal facilities has proven in several countries, including the US, to be the most contentious part of a radioactive waste management program.[10,14] Most of these failed efforts resulted from top-down, federally-mandated siting decisions, made over the objections of local authorities. Even when public participation mechanisms (e.g., public hearings and public comment processes) were established following the expression of public opposition, those efforts did not result in successful siting efforts[15]. As a result, siting efforts (e.g., potential repository locations in Finland, Sweden, and Canada) are moving in the direction of earlier and more meaningful public involvement and decision-making, in order to garner acceptance for building radioactive waste facilities.[10,14]

Promising experiences in other countries indicate that a consent-based process, developed through engagement with states, tribes, local governments, key stakeholders, and the public, offers a greater probability of success than a top down approach to siting[11].

These consent-based siting processes have the following common elements[14]:

- <u>Encourage expressions of interest from a large variety of communities that have potentially suitable sites</u> – As these communities become engaged in the process, the implementing organization must be flexible enough not to force the issue of consent while also being fully prepared to take advantage of promising opportunities when they arise.
- <u>Support negotiations between the implementing organization and potentially affected state, tribal, and local governments, and other entities</u> – It would be desirable for these negotiations to result in a partnership agreement or some other form of legally enforceable agreement with the organization to ensure that commitments to and by host states, tribes, and communities are upheld. All affected levels of government must have, at a minimum, a meaningful consultative role in important decisions. … At the same time, host state, tribal and local governments have responsibilities to work productively with the federal government to help advance the national interest.

Underlying a consent-based siting process are the following siting principles[10]:

- Transparent – … all stakeholders have an opportunity to understand key decisions and engage the process in a meaningful way.
- Phased - … key decisions are revisited and modified as necessary along the way rather than being pre-determined.
- Adaptive – … the process itself is flexible and produces decisions that are responsive to new information and new technical, social, or political developments.
- Standards- and Science-Based – … the public can have confidence that all facilities meet rigorous, objective, and consistently-applied standards of safety and environmental protection.

In recognition of these elements and principles, a UFDC report[15] produced five key findings focused on public attitudes and preferences relevant to the success of a consent-based siting process. These findings were specific to the siting of an interim storage facility, but are broadly applicable to any radioactive waste management facility:

- Matching Facility Features with Community Vision – …the prospect of siting an interim storage or permanent repository is likely to be substantially improved by incorporating facility features that encompass activities that would generate benefits broadly to the nation and future generations, and that explicitly address the risks posed by, and the potential future value of, the radioactive waste. An example is incorporating into the facility a national laboratory that focuses on corrosion studies of the waste containers, degradation studies of the waste, and advances on robotic handling of waste packages.
- Sustainability of Host Community - The offer of benefits to prospective hosts of interim storage facilities poses significant challenges. Generally, the response to benefits as incentives in nuclear facility siting will be conditioned by the broader understanding of the siting policy and the features of the proposed facility. When the facility is seen as beneficial and low risk, we expect that economic benefits would facilitate volunteers. When the magnitude of the risks is in contention, the evidence is moderate that benefits that serve to mitigate or otherwise offset the risk and help to sustain the long-term viability of the host community will be well received by potential hosts.
- Identifying Stakeholders and Who has Veto Authority – … most US residents would prefer to limit the granting of a veto authority to local residents that are most directly affected by the siting, and the chief executive of the state. Findings also make it clear that the public would prefer that the states through their elected governors have a strong role in the consent-based process.
- Characteristics of Viable Host Communities – … early and persistent support from the local population at a prospective host community greatly improves the chance of successful siting of an interim storage facility in a US setting. Generally, when there is a pre-existing temporary storage site near a potential host community, and when local residents are aware of that site, the evidence is moderate that those residents are more likely to express support for a community decision to volunteer to engage in the consent-based siting process.
- Withdrawal of Consent – … while the public broadly supports the BRC recommendation for a consent-based siting process, majorities of survey respondents are also of the opinion that withdrawal of consent is contingent on the stage of the siting process. … withdrawal of consent is widely supported only until a license application has been submitted.

These consent-based siting elements, principles, and findings cover a broad range of technical, logistical, and sociopolitical considerations. Clearly, the implementation of a consent-based process is facility and location specific, and the process must prioritize which of the considerations are most relevant to that particular situation.

Specific to deep borehole disposal in the US, the issuance of the RFI[13] for the DBFT represents the initiation of a consent-based siting process aimed at adhering to these elements, principles, and findings.

III. SITING CONSIDERATIONS FOR DEEP BOREHOLE DISPOSAL

Associated with a consent-based siting process is the development of a set of basic initial siting guidelines. The purpose of specifying siting guidelines is to enhance the likelihood of safe development, operations, and post-closure performance of a radioactive waste disposal system. Siting guidelines provide a means to determine relatively quickly whether a site meets basic suitability requirements, and can inform decisions for proceeding to more detailed site investigation and site characterization studies[14]. In cases where there are multiple volunteer communities and/or candidate sites, the siting guidelines provide a basis for evaluation and comparison of the relative merits.

Specific to deep borehole disposal, siting guidelines should encompass considerations that maximize the probability of successfully (i) drilling and completing a deep large-diameter borehole at a site with favorable geologic, hydrogeochemical, and geophysical conditions, (ii) building and maintaining the associated infrastructure, (iii) conducting surface handling, emplacement, and sealing operations, and (iv) demonstrating long-term post-closure safety. Deep borehole siting guidelines should include potentially disqualifying factors – to identify sites that are clearly unsuitable or inappropriate. Examples of unfavorable features may include: upward vertical fluid potential gradients, presence of economically exploitable natural resources at depth, presence of a high-permeability connection from the waste disposal zone to the shallow subsurface, and significant probability of future volcanic activity.

General considerations for deep borehole disposal siting, which can be used to develop specific guidelines, include technical, logistical, and sociopolitical factors. These considerations are discussed in the following subsections. The translation of these siting considerations to more specific siting guidelines is described in Section IV.

III.A. Technical Factors

Technical considerations include geological, hydrogeochemical, and geophysical conditions potentially relevant to successfully completing a deep borehole field test and demonstrating post-closure safety for a deep borehole disposal system. These include[8,9]:

- Depth to crystalline basement – A depth less than 2,000 m allows for a 2,000 m disposal zone overlain by at least 1,000 m of seals within the crystalline basement.
- Crystalline basement geology – Areas with regionally homogeneous structure and lithology (e.g., plutonic or felsic intrusive rocks) tend to be less likely to have major faults or shear zones, well-connected fracture systems, or recent tectonic activity or seismicity.
- Horizontal stress – A large differential in horizontal stress at depth can be an indicator of potential difficulties in drilling a vertical hole and of borehole instability (e.g., borehole wall collapse and/or an enhanced disturbed rock zone around the borehole).
- Seismicity – Seismic hazard could increase risk during drilling and emplacement. Seismic hazard is also a general indicator of tectonic activity, potential fault movement, and structural complexity.
- Volcanism – Quaternary-age faulting and volcanism is an indicator for potential future tectonic activity or volcanism.
- Topographic relief and hydraulic gradient – Hydraulic gradients in the deep subsurface are generally related to regional variations in topography and can lead to the potential for upward flow in regional discharge areas. However, deep groundwater can be isolated and stagnant in some hydrogeologic settings, in spite of topographic effects.
- Geochemical environment – High salinity and geochemically-reducing conditions tend to reduce radionuclide mobility.
- Geothermal gradient – Geothermal heat flux can lead to the potential for upward hydraulic gradients and is also related to the potential for geothermal drilling.
- Natural resources potential – Petroleum and mineral resources exploration and/or production could lead to human intrusion into the deep borehole and/or impact the release of radionuclides to the overlying sediments.

Evaluation of many of these factors can be accomplished on a preliminary, regional basis with existing data. An accurate compilation of relevant data can be made using a geographical information system (GIS) database. As an example, Figure 2 shows a GIS-compiled map of depth to crystalline basement.

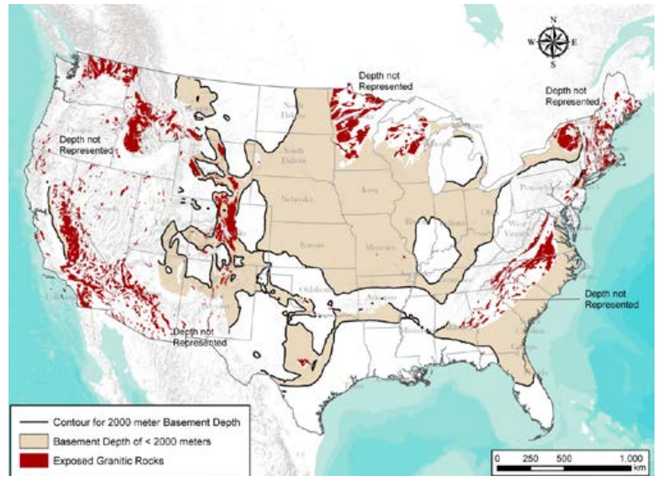

Figure 2. Depth to crystalline basement in the continental US[16].

III.B. Logistical Factors

Logistical considerations include factors relevant to successfully completing the construction and engineering operations associated with a deep borehole disposal facility. These include:

- Availability of drilling contractors and support services – To reduce operational costs, drilling contractors (equipment, services, and materials) capable of drilling a large-diameter hole to 5 km depth should be locally or regionally available.
- Regulations and permitting – Legal and regulatory requirements associated with drilling, construction of surface facilities, and waste handling and emplacement must be achievable. The regulatory environment is different in different states and for Federal versus private land.
- Site area and access – There should be sufficient area for drilling, surface handling, and emplacement operations. There should also be reasonable access to roadways and/or railways for transportation of waste and other materials.

III.C. Sociopolitical Factors

Social and political considerations include factors relevant to public opinion and acceptance. These include[9]:

- Proximity to population centers
- Opinion (e.g., support or opposition) of state and local entities and other stakeholders towards nuclear facilities
- Willingness to participate in a consent-based process

The sociopolitical climate can be enhanced through implementation of a consent-based process, in particular a process that incorporates the five key UFDC findings outlined in Section II. Additionally, early engagement with local and regional stakeholders is helpful, and engagement with scientific communities (e.g., state geological surveys and state university faculty) provides local and regional geoscientific knowledge.

IV. SITING GUIDELINES FOR DEEP BOREHOLE DISPOSAL

The siting considerations outlined in Section III provide a basis for the development of specific siting guidelines for a deep borehole disposal facility. As noted in Section I, DOE has issued an RFI seeking volunteer communities to host the DBFT. The RFI[13] contained a set of preferred guidelines for a site for the DBFT. These preferred guidelines are listed below – ordered to correspond to the siting considerations listed in Section III:

- Less than 2 km depth to crystalline basement
- No known major crystalline basement shear zones or major tectonic features
- Less than 2% probability within 50 years of peak ground acceleration greater than 0.16 g from a seismic event (generally indicative of area of tectonic stability)
- Distance to Quaternary age volcanism greater than 10 km
- Distance to Quaternary age faulting greater than 10 km
- Distance greater than about 100 km to topographic slope of greater than 1º to avoid deep groundwater circulation
- Geothermal heat flux less than 75 mW/m^2
- Low density of petroleum drilling
- Not at or proximate to a strategic petroleum reserve site
- Not near an urban area
- Site area greater than 1 km^2 2 (so that there is ample area for drilling operations)
- Lack of known existing surface or subsurface anthropogenic radioactive contamination

The RFI[13] states that interested responders should discuss how any proposed host site meets the above preferred location guidelines and state and local government approval requirements. The RFI also identifies, separate from the siting guidelines, potential technical and economic benefits. Specifically, it states that "A community hosting the DBFT may benefit by gaining a more thorough understanding of the local subsurface geologic and hydrologic characteristics that may permit better community management of local resources. Economic and scientific aspects of the DBFT also may benefit the local community, policy decision makers and regulators, local and state government, universities, and other regional stakeholders in such other subsurface technical areas such as geothermal energy production, fossil energy production, and carbon sequestration amongst others." [13]

Collectively, the siting guidelines and associated statements in the DBFT RFI capture the key siting considerations outlined in Section III for a deep borehole disposal facility. It is expected that, as interested potential host communities respond to the RFI, that there will be a process to evaluate proposed sites against the siting guidelines. However, this evaluation process has not yet been publicized. At this point, the RFI simply states, "This RFI is issued solely to request information that may be used by DOE to develop and issue an RFP." [13]

V. SUMMARY AND CONCLUSIONS

This paper describes the initiation of a consent-based siting process for a deep borehole field test, designed to evaluate the feasibility of siting and operating a deep borehole disposal facility. A set of siting guidelines for siting the DBFT were developed, starting from a broader set of general considerations for siting a deep borehole disposal facility for SNF and/or HLW. The siting guidelines for the DBFT, outlined in an RFI for potential host communities, include technical, logistical, and sociopolitical factors.

The technical and logistical guidelines for the DBFT are similar to those that would be expected for a deep borehole disposal facility: sufficient depth to relatively homogeneous crystalline basement, absence of recent seismic or volcanic activity, absence of significant hydraulic or thermal gradients, low natural resources potential, distant from population centers.

The consent-based process for siting the DBFT (i.e., the issuance of the RFI) addresses initial sociopolitical considerations. However, these considerations must continue to be addressed as the site evaluations, site selection, and DBFT implementation proceed.

With regard to consent-based siting for an operating SNF/HLW disposal facility, actual disposal of nuclear waste would likely be a much more controversial activity from a social and political perspective than the DBFT. Site selection for a disposal program would involve a more extensive stakeholder outreach program and more complex political engagement than locating the DBFT. Site selection for a deep borehole disposal facility would also involve consideration of waste transportation costs and infrastructure, which could vary considerably depending on the disposal site location relative to waste storage or nuclear power plant locations. A deep borehole disposal facility would also require a larger site and a longer-term commitment than the DBFT, which would be important considerations in the site selection process.[8]

ACKNOWLEDGEMENTS

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. This paper is Sandia publication SAND2014-xxxxC.

REFERENCES

1. M. T. O'BRIEN, L. H. COHEN, T. N. NARASIMHAN, T. L. SIMKIN, H. A. WOLLENBERG, W. F. BRACE, S. GREEN, and H. P. PRATT. *The Very Deep Hole Concept: Evaluation of an Alternative for Nuclear Waste Disposal*. LBL-7089, Lawrence Berkeley Laboratory, Berkeley, CA (1979).
2. WOODWARD-CLYDE CONSULTANTS. *Very Deep Hole Systems Engineering Studies*. ONWI-226, Office of Nuclear Waste Isolation, Columbus, OH (1983).
3. C. JUHLIN and M. SANDSTEDT. *Storage of Nuclear Waste in Very Deep Boreholes: Feasibility Study and Assessment of Economic Potential*. SKB 89-39, Svensk Kärnbränslehantering AB, Stockholm Sweden (1989).
4. NIREX. *A Review of the Deep Borehole Disposal Concept*. Report N/108, Nirex Ltd., U.K. (2004).
5. H. H. HESS, J. N. ADKINS, W. B. HEROY, W. E. BENSON, M. K. HUBBERT, J. C. FRYE, R. J. RUSSELL, and C. V. THEIS. *The Disposal of Radioactive Waste on Land, Report of the Committee on Waste Disposal of the Division of Earth Sciences*. Pub. 519, National Academy of Sciences - National Research Council, Washington, D.C. (1957).
6. P. V. BRADY, B. W. ARNOLD, G. A. FREEZE, P. N. SWIFT, S. J. BAUER, J. L. KANNEY, R. P. RECHARD, and J. S. STEIN, *Deep Borehole Disposal of High-Level Radioactive Waste*. SAND2009–4401, Sandia National Laboratories, Albuquerque, NM (2009).
7. B. W. ARNOLD, P. V. BRADY, S. J. BAUER, C. HERRICK, S. PYE, and J. FINGER, *Reference Design and Operations for Deep Borehole Disposal of High-Level Radioactive Waste*. SAND2011–6749, Sandia National Laboratories, Albuquerque, NM (2011).
8. DOE. *Research, Development, and Demonstration Roadmap for Deep Borehole Disposal.* FCRD-USED-2012-000269, US Department of Energy Used Fuel Disposition Campaign, Washington, D.C. (2012).
9. DOE. *Deep Borehole Disposal Research: Demonstration Site Selection Guidelines, Borehole Seals Design, and RD&D Needs.* FCRD-USED-2013-000409, US Department of Energy Used Fuel Disposition Campaign, Washington, D.C. (2013).
10. BRC. *Report to the Secretary of Energy*, Blue Ribbon Commission on America's Nuclear Future, Washington, D.C. (2012).
11. DOE. *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste.* US Department of Energy, Washington, D.C. (2013).
12. SNL. *Project Plan: Deep Borehole Field Test.* SAND2014-18559R, FCRD-UFD-2014-000592, Rev 0, Sandia National Laboratories, Albuquerque, NM (2014).
13. DOE. *Request for Information (RFI) – Deep Borehole Field Test.* Solicitation Number DE-SOL-0007705, US Department of Energy Idaho Operations Office, Idaho Falls, ID (2014).
14. R.P. RECHARD, B. GOLDSTEIN, H. GREENBURG, J.A. BLINK, W.G. HALSEY, M. SUTTON, F.V. PERRY, S. LEVY, T.A. COTTON, J.T. CARTER, and A. O'NEAL DELLEY. *System-Wide Integration and Site Selection Concepts for Future Disposition Options for UNF and HLW.* FCRD-USED-2011-000335, US Department of Energy Used Fuel Disposition Campaign, Washington, D.C. (2011).
15. H.C. JENKINS-SMITH, C.L. SILVA, K. GUPTA, J. RIPBERGER, R.P. RECHARD, R. ROGERS, M. PENDLETON, and L. PRICE. *Summary of Approaches for Consent-Based Siting of Radioactive Waste Management Facilities: Evidence-Based Considerations and Case Studies.* FCRD-NFST-2013-000113, US Department of Energy, Nuclear Fuel Storage and Transportation Planning Project, Washington, D.C. (2013).
16. F.V. PERRY, R.E. KELLEY, P.F. DOBSON, and J.E. HOUSEWORTH. Regional Geology: *A GIS Database for Alternative Host Rocks and Potential Siting Guidelines*. LA-UR-14-20368, FCRD-UFD-2014-000068, Los Alamos National Laboratory, Los Alamos, NM (2014).