UNITED STATES
NUCLEAR WASTE TECHNICAL REVIEW BOARD
2300 Clarendon Boulevard, Suite 1300
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July 30, 2013

Dr. Peter Lyons
Assistant Secretary for Nuclear Energy
U.S. Department of Energy
1000 Independence Avenue SW
Washington, DC 20585

Dear Dr. Lyons:

In your presentation at the Board's April 16, 2013, meeting in Richland, Washington, you indicated that the Department of Energy (DOE) is developing a research and development (R&D) plan for deep borehole disposal as part of its *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste Disposal*. As you develop your R&D plan, the Board makes three recommendations.

- There are drilling, casing, and sealing challenges associated with the disposal of spent nuclear fuel and high-level waste in deep boreholes. The different components of the deep (5 km) borehole disposal system (e.g., drilling, emplacement and sealing) should be investigated in a logical stepwise sequence starting at the bench-scale, progressing to *in situ* tests, prior to implementing a full-scale pilot deep borehole.

- A major challenge will be the characterization of the host rock at great depth. The petrologic, hydrologic and geochemical characteristics of the rock units at depth may vary considerably. DOE should use international collaborations with those countries that have operating underground research laboratories, such as Switzerland and Sweden, to identify and address issues related to the characterization of rock at depth and to understand how the heterogeneity of petrologic, hydrologic and geochemical characteristics could affect the drilling, casing, and sealing of the proposed borehole drilling systems.

- Due to limitations on the size of the package that can be emplaced in a deep borehole, a major challenge will be the dismantling of spent nuclear fuel assemblies and the consolidation of the spent nuclear fuel rods into smaller packages. Such dismantling and consolidation will require new facilities, and

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entail additional cost and potential exposure of workers. DOE should assess these impacts as part of the deep borehole disposal R&D plan.

It is important to acknowledge that the development of deep borehole disposal systems, as described in the Blue Ribbon Commission on America's Nuclear Future report to the Secretary of Energy, would not eliminate the need for a mined geologic repository. Because deep borehole disposal is in the earliest stages of development, significant technological challenges must be resolved. Also a large number of deep boreholes would be required (the spent nuclear fuel proposed for Yucca Mountain alone would require about 600 boreholes). Because of these technological challenges and the significant scale of a deep borehole disposal program, the Board reiterates its long-standing support of mined geologic disposal and notes that virtually every national nuclear waste disposal program is pursuing development of a mined geologic repository for disposing of spent nuclear fuel and high-level radioactive waste.

As described in the enclosed update of the fact sheet on Deep Borehole Disposal, which will soon be posted on the Board's website, the technical challenges associated with drilling, emplacing, and sealing deep boreholes coupled with the scale of the effort that would be required to dismantle and package the spent nuclear fuel suggest that deep borehole disposal may prove to be extremely complex. Further, the expansion to many boreholes in different regions of the country and in different geologies make full implementation difficult. Consequently, in the Board's view, research related to deep borehole disposal should not delay higher priority research on a mined geologic repository.

The Board looks forward to reviewing DOE's work in this area at a future Board meeting.

Sincerely,

{Signed by}

Rodney C. Ewing
Chairman

Enclosure

DEEP BOREHOLE DISPOSAL OF SPENT NUCLEAR FUEL AND HIGH-LEVEL WASTE

BACKGROUND

Deep borehole disposal of spent nuclear fuel (SNF) from nuclear power plants or solidified high-level radioactive waste (HLW) from the reprocessing of nuclear fuel is a concept that dates from the mid-1970s. The concept was considered again in the 1990s and early 2000s (e.g., in Sweden[1] and the UK[2]). Most recently it has been mentioned as an alternative to disposing of SNF and HLW in a mined geologic repository.[3,4] In 2012, the Blue Ribbon Commission on America's Nuclear Future (BRC) recommended further research and development to help resolve some of the uncertainties associated with deep borehole disposal.[5] The BRC particularly emphasized that deep borehole disposal might be considered for certain forms of waste that have essentially no potential for reuse.

CONCEPT

The most recent concept of deep borehole disposal being discussed in the U.S. involves drilling a borehole to a depth of about 5,000 m (about 16,400 ft) in crystalline basement rock, emplacing waste packages containing consolidated SNF assemblies or solidified HLW in the lower 2,000 m (about 6,600 ft) of the borehole, and sealing the upper 3,000 m (about 9,800 ft) of the borehole.[4] The waste packages would be emplaced individually or as a string of 10-20 packages. A single borehole could contain up to 400 waste packages, each approximately 5 m (about 16 ft) in length. Approximately 1,000 boreholes would be needed to dispose of a projected U. S. inventory of 109,300 metric tons of spent nuclear fuel and high-level waste and current plans call for a series of dense arrays of boreholes [~100 boreholes in a 2-3 km^2 (1.2-1.9 mi^2) region].[4]

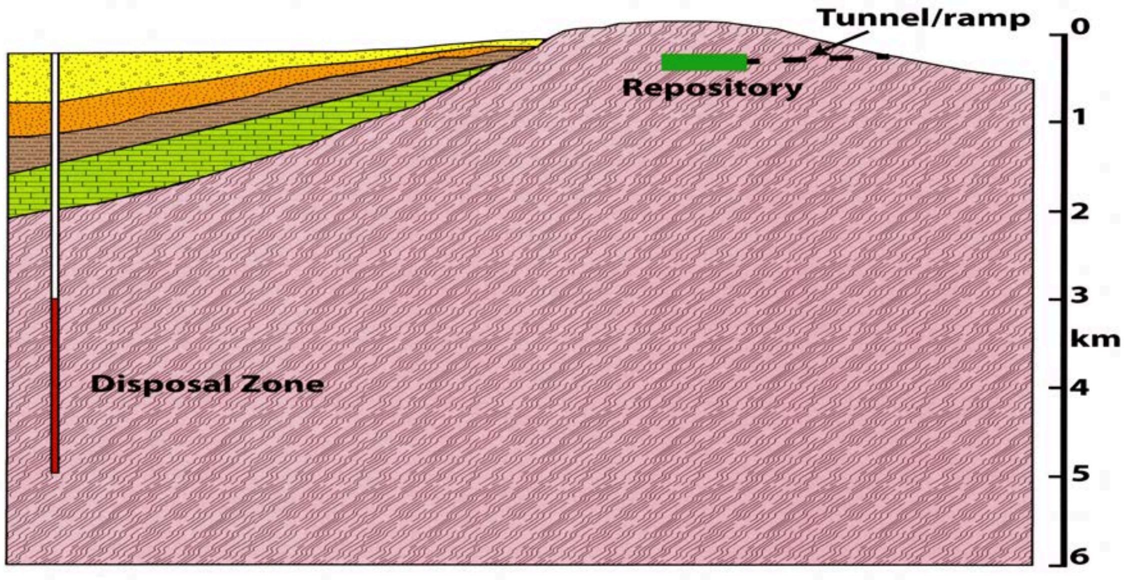

Figure 1. Schematic section of crystalline basement rock, with overlying sedimentary rocks, depicting the concept of deep borehole disposal of nuclear waste (red), in contrast to disposal in an underground mined repository (green shaded box) approximately 500 m (approximately 1600 ft) below the surface (figure modified from Gibb[6]). Crystalline basement rocks include intrusive igneous rocks such as granite and metamorphic rocks such as schist and gneiss (depicted above) and these rocks can have considerable variability in chemical and physical properties.

POTENTIAL ADVANTAGES OF DEEP BOREHOLE DISPOSAL

- Because the proposed disposal zone of a deep borehole is significantly deeper than that of a mined geologic repository (Figure 1), waste isolation from the biosphere and shallow ground water systems could be enhanced by several factors including:
  - The greater depth of emplacement
  - The low permeability of the host rock at depth, as well as greater distances to the accessible environment, which would result in very long travel times
  - The reduced buoyancy of higher density, highly saline, groundwater assumed to be present at great depth
  - The reducing conditions at depth (i.e., low concentrations of oxygen), which would result in greater geochemical isolation of the waste due to the lower solubility and mobility of some radionuclides, such as the actinides.
- Multiple disposal sites could be located near nuclear power plants with suitable geologies, thus reducing the need to transport SNF.

TECHNICAL CHALLENGES ASSOCIATED WITH DEEP BOREHOLE DISPOSAL

- **Drilling technology** – The completion of a borehole with a diameter of up to 0.5 m (about 1.6 ft) to a depth of 5,000 m (about 16,400 ft) has never been demonstrated. Doing so in crystalline rock would require the development of technologies well beyond the experience and practice of the oil industry. Deep boreholes in crystalline rock with smaller diameters drilled for scientific investigations have been plagued by complications related to spontaneous deformation of the borehole wall caused by anisotropic stress fields at depth.

- **Casing and sealing technology** – The emplacement of casing at such depth in a potentially deformed borehole and sealing of the metal casing-rock interfaces are significant technological challenges. The potential for inadequate sealing between the casing and surrounding rock is a major concern for the deep borehole concept.[7] An insufficient seal might be difficult to detect by well logging and could provide a hydraulic pathway to the surface.

- **Consolidation and repackaging of waste** – Dismantling commercial SNF assemblies that are in dry storage at nuclear utility sites would be necessary to accommodate the small size of the waste packages that could be used for disposing of SNF in deep boreholes. Repackaging SNF involves extensive fuel handling that could lead to fuel rod breakage and potential radiation exposure to workers. The criticality and thermal implications of consolidating the SNF rods also must be considered. Further, there are many types of DOE-owned SNF of various sizes that might be problematic for consolidation. In addition, existing and planned canisters of vitrified HLW are all 0.61 m (2.00 ft) in diameter and would not fit into any of the currently proposed borehole configurations.

- **Problems with emplacement of waste packages** – With the emplacement of hundreds of waste packages, the possibility of some packages becoming stuck in a borehole must be considered. Normal strategies for dealing with downhole obstacles, such as drilling through the obstructions or forcing the container down the borehole, could not be used when emplacing highly radioactive waste packages.

- **Effective borehole seals** – Effective, long-term performing materials would have to be developed and demonstrated for sealing the drill hole above the emplaced waste. A number of approaches have been proposed, such as backfilling with materials like concrete and bentonite or taking advantage of the heat produced by the waste to encapsulate waste packages in melted rock. However these approaches have not been subjected to *in situ*, underground testing.

- **Retrieval of emplaced waste** – Retrieving waste after it has been emplaced and sealed in a deep borehole would present significant technical and safety challenges. Current federal regulations require that a retrieval option be maintained after emplacement of waste in a deep geologic repository. That requirement would be difficult or impossible to meet using sealed, deep boreholes for permanent disposal of SNF or HLW.

- **Complexity of site characterization** – Implicit in most analyses of the feasibility of deep borehole disposal are the assumptions that less site characterization would be needed at great depth because conditions likely would be more homogeneous and that potentially advantageous conditions (i.e., a reducing environment, low isotropic permeability, and highly saline, density-stratified conditions) are found everywhere**.** However, surface geologic exposures of formerly mid-crustal rocks do not support these simple assumptions. Deeply buried basement rock can have considerable variability in chemical and physical properties, and there are too few well-characterized scientific deep boreholes to make these generalizations. The characterization of deep, heterogeneous crustal rocks will require the development of new geophysical techniques that can map rock properties tens of meters away from the borehole, particularly fracture zones that could channelize flow.

- **Role of multiple barriers** – A major tenet of nuclear waste disposal is the use of multiple barriers, i.e., engineered and natural barriers that work together to ensure the long-term containment of radionuclides. The strategy being developed in the U.S. for deep borehole disposal of SNF relies primarily on the geology and the depth of burial. No credit is taken for the waste package or the waste form.

CONTINUED NEED FOR A MINED GEOLOGIC REPOSITORY

The deep borehole concept, as described by the BRC, does not eliminate the need for a mined geologic repository for disposal of those waste that are deemed unsuitable for deep borehole disposal.

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4. Brady, P., B. W. Arnold, G. A. Freeze, P. N. Swift, S. J. Bauer, J. L. Kanney, R. P. Rechard, J. S. Stein, 2009, Deep borehole disposal of high-level radioactive waste: Sandia Report SAND2009-4401, 75 p.
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The U.S. Nuclear Waste Technical Review Board was established in the 1987 amendments to the Nuclear Waste Policy Act (NWPA). The Board evaluates the technical and scientific validity of Department of Energy (DOE) activities related to implementing the NWPA and provides objective expert technical advice on nuclear waste management to Congress and the Secretary of Energy. The Board is required by law to report its findings and recommendations at least two times each year to Congress and the Secretary.

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