Underground Exploration and Testing at Yucca Mountain

A Report to Congress
and
the Secretary of Energy

Nuclear Waste Technical Review Board
October 1993

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This report is the eighth in a series of reports by the Nuclear Waste Technical Review Board. Reports are available from the Government Printing Office, Washington, D.C., or from the Board's office in Arlington, Virginia.

Executive Summary

Underground exploration and testing are [illegible] components of the DOE's site characterization efforts at Yucca Mountain, Nevada. During the past [illegible] years, the DOE's plans for exploration and testing [illegible] have evolved substantially, and many improvements have been made. The DOE's current program involves extensive tunneling through the [illegible] at Yucca Mountain with the goal of gaining access to the [illegible] at the site. It is especially important to thoroughly characterize [illegible] of the faults that cross the site, as well as the site's fractures [illegible]. Once tunnels have been excavated, scientists also will be able to conduct large-scale tests, which are necessary to assess how the natural and engineered barriers will perform under conditions similar to those in a potential repository for spent nuclear fuel and high-level waste. Data gathered during these tests will be used to evaluate site suitability, to predict long-term performance of the potential repository system, and to support a license application — should the site prove suitable.

In this report, the Board reviews the status of the DOE's underground exploration and testing program. In addition to a number of detailed recommendations, the Board makes three general recommendations, which are summarized below. The Board would like to emphasize that its recommendations can be implemented by the DOE without slowing the momentum of important site-characterization activities now under way at Yucca Mountain.

The Board concurs with the overall objectives established by the DOE for underground exploration and testing at Yucca Mountain and supports many of the changes that have been made to the program in the past year. However, the Board remains concerned that because of past delays in beginning underground exploration and attempts to comply with an early plan and schedule, the DOE is making important technical decisions about the layout and sequencing of underground exploratory facilities without sufficient analysis. [illegible] Until recently, the DOE had planned to rapidly [illegible] portal and [illegible] testing [illegible], which the Board [illegible] being extended rather than shortened [illegible]. The Board supports the DOE's [illegible] north portal loop has been completed [illegible] test area and the Calico Hills [illegible]

The Board believes, however, that the Yucca Mountain project [illegible] strategy for exploration and testing. To better assess [illegible] of the underground exploration and testing program, *the Board recommends that the DOE [illegible] a comprehensive [illegible] priorities [illegible] design and [illegible]*

This strategy should be based on specific intermediate goals and be consistent with the scientific priorities of site characterization, realistic funding expectations, and the efficient development of the underground exploratory facility. With such a strategy, the DOE could simplify what is still an overdesigned facility, which includes excessive test support facilities and utilities.

Thermal testing should be an important component in any comprehensive strategy for exploration and testing at Yucca Mountain. *The Board recommends the resumption of underground thermal testing as soon as possible.* Since testing in the core test area is not scheduled to begin until early 1998, the DOE should consider reinitiating underground thermal testing outside the repository area. This will allow the DOE to establish a continuous testing program for the development of instrumentation and procedures and to gain as much testing experience as possible *prior* to initiating testing in the core test area.

The Board believes that the excavation of the exploratory facility could be accomplished more quickly and at less cost if the tunnels and support facilities were designed only to meet the needs of exploration and testing. For example, after the portal-to-portal loop has been completed, excavation of tunnels off the loop and in the core test area can begin using a 16- to 18-ft-diameter tunnel boring machine. The design of the core test area, where critical thermal testing will be conducted, should be simplified to allow excavation using a full-face tunnel boring machine. Although extensive tunneling is required, the DOE should continue to reduce the extent of surface and subsurface facilities and utilities to reflect the revised sequential excavation plan and the specific needs of the exploration and testing program.

If the Yucca Mountain site proves suitable and is licensed for construction, the exploratory facility is to be integrated into the repository design. Therefore, the design of the exploratory facility should remain as compatible as possible with potential repository designs. The DOE's recent proposal to reduce tunnel gradients in the exploratory facility makes it more compatible with existing repository designs.

The Board recognizes the complex regulatory and oversight constraints facing the U.S. high level waste program and the challenges inherent in managing such a large, first of a kind scientific and engineering project. However, the Board believes that a wealth of industry expertise and experience exists from which the DOE could draw more effectively. To assist program managers and to take maximum advantage of existing experience in the underground construction industry, the *Board recommends that* — as is common practice on large construction projects — *the DOE establish a geoengineering board with expertise in the*

[illegible]

[illegible] scientific community's [illegible] concerns [illegible] Yucca Mountain [illegible] factors [illegible] first being made [illegible] testing and evaluation [illegible]

As it stated in its March [illegible] management program [illegible] The Board finds that [illegible] Yucca Mountain [illegible] the site characterization [illegible] Yucca Mountain project, the DOE [illegible] system [illegible] decisions [illegible]

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Introduction

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Background

In March 1993, the Board published a *Special Report* (NWTRB, March 1993) to the Congress and the Secretary of Energy. That report outlined three critical concerns that have affected the technical components of the DOE's civilian radioactive waste management program: (1) the program's overly optimistic schedules, (2) the need for a well-integrated overall waste management plan that includes transportation, storage, and disposal of radioactive wastes, and (3) the effectiveness of program management. These issues have affected the program *overall*, but the schedule and management issues raised in that report also have affected site-characterization efforts — especially the DOE's approach to underground exploration and testing at Yucca Mountain.

Underground exploration and testing will require extensive tunneling[1] through the mountain at various levels and across all geologic units to allow scientists to visually examine the complex geology at the site. It is especially important to determine the character and extent of the faults that cross the site[2] and to gain an understanding of the site's complex hydrogeology and geochemistry. Once the tunnels have been excavated, they will host an underground exploratory facility from which further testing will take place.

Excavating the underground exploratory facility, designated the exploratory studies facility, is an important milestone in the DOE's waste management program because it is key to achieving a number of other intermediate program goals. For example, if there are any "fatal flaws," or major disqualifying features that might lead to abandoning the site, they will most likely be revealed through the excavation of exploratory tunnels. In addition, once the exploratory facility has been excavated, scientists will be able to initiate important in situ tests, such as thermal tests, which are necessary to evaluate how the natural geologic and engineered barriers actually will perform under conditions similar to those in a potential repository once waste has been emplaced. Data gathered during these tests will be used to determine site suitability, to predict long-term performance of the entire repository system, and to support application for the construction license — should the site prove suitable.

The exploratory facility also has the potential to become more than just a location for underground testing. If the site is judged suitable and is licensed for repository construction, major parts of the exploratory facility could be integrated into the repository. Therefore, the design of the exploratory facility should be compatible with any potential repository designs.[3]

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[1] *Tunneling* is referred to as an underground construction activity that results in a permanent facility. This contrasts with mining, which is the process of extracting mineral deposits from the earth.

[2] The faults and fracture zones in the prospective repository horizon at Yucca Mountain tend to be near vertical, making their detection and characterization more feasible by tunneling.

[illegible]

[illegible]

Exploration and Testing — Designing and Excavating the Exploratory Facility

According to a DOE presentation to the Board on April 22, 1993, the underground exploration and testing program has a number of key objectives including gathering otherwise unobtainable data on the major geologic features (units, faults, and contacts) throughout the mountain; gaining access to the underground so that various in-situ large-scale thermal, hydrologic, and mechanical tests can be initiated; and allowing a continuous, early look at the natural system to assess site suitability and provide critical data for repository design.

The Board concurs with these general objectives. And, in the following discussion offers suggestions for developing an improved strategy for underground *exploration* and *testing* at the Yucca Mountain site[4] that is carefully linked to the design and approach to excavating the underground exploratory facility.

Strategies for Exploration and Testing

The DOE's plans for exploration and testing have changed during the past four years, and much progress has been made. Recently, several changes have been proposed to further improve the program. Because the DOE's current plans and sequence for exploration and testing are still evolving, the Board would like to use this report to outline what it believes would be key elements in a comprehensive strategy for exploration and testing.

Explore across the geologic block

Since its first meetings in 1989, the Board has emphasized the importance of gaining early access to the underground at Yucca Mountain by excavating tunnels across major geologic features at the site. The geology of the site should be explored and tests conducted not only in the welded tuff[5] at the repository level but also in the nonwelded tuff above and below the repository level.

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[4] As used here, *exploration* of a site means excavating tunnels to allow human access for relatively short-term observations of geologic conditions. *Testing* means conducting longer-term scientific experiments in the excavated tunnels.

[5] *Tuff* is a rock composed of compacted volcanic ash. It is either welded — consolidated by heat, pressure, and possibly the introduction of cementing minerals — or nonwelded. *Welded* tuff tends to be hard and highly fractured. Nonwelded tuff is usually porous and often relatively soft.

1. The DOE should first explore the major geologic features (above and at the repository level) by excavating the portal-to-portal loop (see Figure 2). Plans for the first phase of underground exploration call for excavating a ramp from the north portal down through the nonwelded tuff above the repository, and through the Imbricate Fault zone before reaching the repository level in the Topopah Spring welded tuff. The tunnel will then proceed across the Topopah Spring unit, crossing the Ghost Dance Fault at two places, in the central portion of the geologic block and again at the south end of the block, where the fault has a greater vertical offset. From there, excavation proceeds up the south ramp to the south portal. This first excavation sequence, which does not include excavation of any other tunnels, is referred to in this report as the *portal-to-portal loop.*

During excavation of the portal-to-portal loop, perched water and seepage may be observed and sampled. However, the only tests that should be undertaken during the excavation of the portal-to-portal loop would be to gather initial data on hydrologic properties across fault zones. To do this, near-horizontal boreholes will be drilled. They should be planned so that drilling can be conducted without interrupting the advance of the tunnel boring machine.[7] No other delays to machine operation should be allowed unless they are to gather critical, repository-relevant scientific data that would later be unrecoverable. After the portal-to-portal loop has been excavated, tunnels can be excavated east and west to penetrate the Imbricate Fault and Solitario Canyon Fault zones.

According to the DOE, limited core will be taken from the underground borings. Core will be drilled as soon as possible after the fault zone is excavated. The intent is to gain access to the borehole as soon as possible to reduce the effect of air exchange with the surrounding air mass. Sensitive temperature measurements made in the boreholes will be used to indicate water movement in the fault zone.

The ESF Alternatives Study (SNL 1991) calls for the tunnel boring machine to cross the Ghost Dance Fault zone at an oblique angle. Often, faults are not present as single surfaces but occur in zones comprising a series of individual fault planes as well as regions of fractured, crushed, and altered rock. Recent surface mapping has indicated, for example, that the Ghost Dance Fault zone at Yucca Mountain may be as wide as 1,000 ft. Intersecting it at a small angle during excavation of the portal-to-portal loop could mean tunneling through extensive lengths of the zone, which could cause serious support problems and slow machine advance.

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[7] One approach might be to mount the drill rig and support equipment on a platform that bridges the roadway behind the tunnel boring machine so that supplies can continue to the machine while boring is under way. This should be easy to do, especially if rail transport (with its smaller envelope) is used rather than rubber-tired vehicles.

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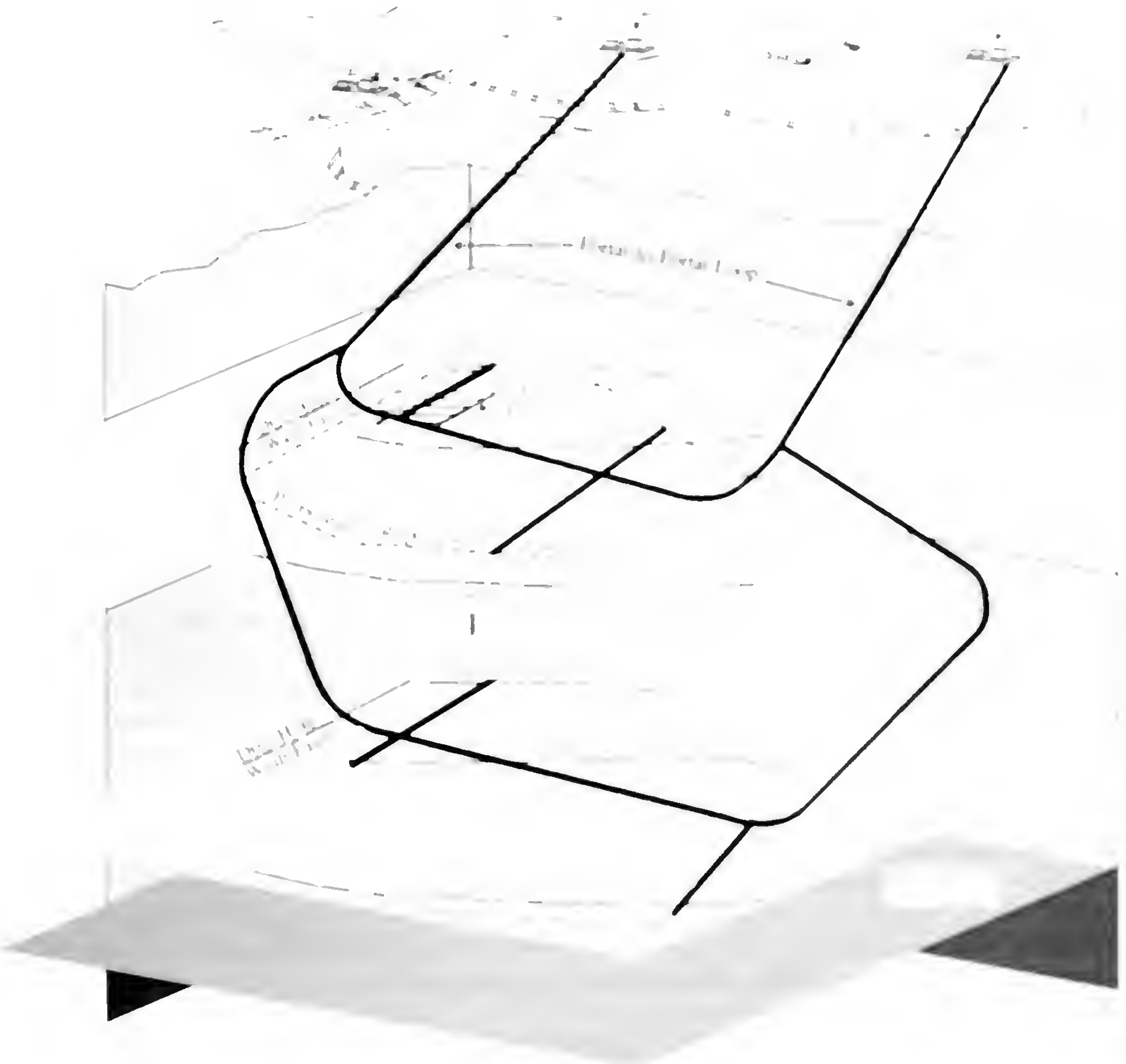
Petal to Petal Loop

[illegible]

At the Board's July 1993 meeting, the DOE proposed several changes to the design of the exploratory facility; one calls for realigning the main tunnel so that it parallels the Ghost Dance Fault. Short, smaller diameter tunnels would later be excavated off the main tunnel to allow penetration and exploration of the Ghost Dance Fault at several points. This realignment could provide additional flexibility to the exploration and testing program and reduce the risks normally associated with excavating large tunnels through fault zones. However, since there may be secondary faults adjacent to the primary Ghost Dance Fault zone, flexibility in locating the main drift will be necessary so that it does not run along a secondary fault (it may not be possible to avoid more closely spaced fractures that parallel the faults).

2. The DOE should continue to thoroughly analyze the advantages and disadvantages of exploring in the Calico Hills. The Calico Hills consists of nonwelded tuff located below the repository level. Because the Calico Hills unit is a potential barrier to the transport of radionuclides from the repository down to the regional ground-water table, it is necessary to understand thoroughly the nature of jointing and faulting at this level.[7]

Based on the results of the Exploratory Studies Facility Alternatives Study and the Calico Hills Risk/Benefit Analysis (YMPO 1991), the DOE concluded in 1991 that early access to the Calico Hills would provide a net benefit when considering (1) possible postclosure risks, (2) the degree of scientific confidence in testing, (3) the potential for regulatory delay, (4) variations in program cost, and (5) the potential for phasing the tests. Examining the characteristics of the same fault zones *directly below* the repository level in the Calico Hills will provide valuable information on the flow of ground water through the unsaturated zone of Yucca Mountain.[8] As at the repository level, additional east-west drifts would be excavated off the main tunnel through the Calico Hills to allow a full east-west traverse of the major north-south trending features.

Recently, the DOE has mentioned budget constraints as a possible reason to forgo exploration across the block below the repository horizon in the Calico Hills. The Board strongly believes that any decision to forgo exploration of the Calico Hills using tunneling should be based on a thorough scientific and technical analysis of site-characterization issues.

[7] Faulting and fracturing in the Calico Hills unit is likely to be much different from that in the welded tuffs of the Topopah Spring (i.e., the repository level) because the welded tuffs are harder and possibly highly fractured in the fault zones, whereas soft nonwelded tuffs are not as highly fractured and may offer reduced fracture permeability along faults.

[8] To be able to evaluate the nature of faults at different levels it would be desirable to excavate portions of the tunnel in the Calico Hills unit directly below the portal to portal loop.

Initiate testing

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

a nine-month period in welded tuff at Rainier Mesa, Nevada Test Site. Tests consisted of a single heater simulating *horizontal* borehole emplacement of a small waste package (an alternative to the vertical borehole concept then favored). Because no additional testing has been conducted since the G-Tunnel effort was terminated in 1989, these data, which are very limited in scope, provide the only underground thermal test data available to the program.

Because of this four-year hiatus in underground thermal testing, the program currently lacks sufficient field testing experience, proven instrumentation for underground testing, and a well-developed testing strategy. The present DOE plans call for thermal testing to be conducted in the core test area off the main tunnel of the portal-to-portal loop. Unfortunately, a recent DOE schedule shows the reinitiation of thermal testing in the core test area has continued to slip during the last 16 months, from November 1996 to early 1998 (DOE 1993). Underground thermal testing should be reinitiated as soon as possible. The Board believes that it is critical to develop instrumentation and procedures and gain as much testing experience as possible *prior* to initiating testing in the core test area. The Board places high priority on understanding the effects of thermal loading on a potential repository through a *continuing* program of thermal testing.[11]

An overall testing strategy presented to the Board by the DOE in July as an "ideal" approach calls for at least three years of prototype underground thermal testing (outside of the repository block). This would be followed by testing in the core test area consisting of two or more years of test planning, ten years of testing, and one-and-a-half years of analysis and data reduction.[12] All underground test configurations would be designed to simulate the anticipated repository configuration.[13]

Several proposals for reinitiating prototype underground thermal testing have been presented to the Board. At a Board meeting on the exploratory facility in November 1992, the DOE reviewed the advantages of developing an in situ prototype thermal test facility at Busted Butte (several miles south-east of Yucca Mountain in an outcropping of Topopah Spring welded tuff). At the July 1993 Board meeting in Denver, the DOE made a strong case for initiating a large heated-block test, which was referred to as an "off-block prototype in situ thermal

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[11] In situ heater tests of sufficient size to include scaling and heterogeneity effects are needed to test fundamental hypotheses. It was proposed that in situ testing be defined to meet two needs: short to medium duration (i.e., 1 to 7 years) to support and defend license application, and long duration (i.e., 50 to 200 years) to provide performance confirmation (Wilder 1993).

[12] Ibid.

[13] Ibid. One configuration would make use of 21 5.5 Kw heaters in three parallel drifts, simulating repository waste emplacement drifts.

test. The plan [illegible] would [illegible] installing [illegible] continue for five to [illegible] years. [illegible] obtained would be of limited [illegible] of a potential repository.

Given the potential [illegible] facility [illegible] and [illegible] underground testing facility [illegible] timely and cost-effective [illegible] excavation of the [illegible] site.

3. Hydrologic [illegible] of the twelve planned [illegible] some percolation test [illegible] DOE [illegible] to these tests [illegible] YMPO [illegible] The DOE [illegible] conduct these tests [illegible] fractures [illegible] during the [illegible]

4. Geomechanical [illegible] Most of the needed data [illegible] can be gathered through [illegible] with the [illegible] appropriate [illegible]

[illegible]

Establish exploration and testing strategies, priorities, and goals

The DOE should develop a *comprehensive strategy* for exploration and testing. The current revised plans for conducting sequential exploration and testing, although much improved, are still evolving. The plans appear to reflect some degree of general prioritization; however, no detailed documentation has been made available to the Board that identifies either specific priorities or a basis for any prioritization. This lack of a comprehensive testing strategy is reflected in the current complex design of the underground facility, which contains excessive test support facilities and utilities. Specific milestones for excavation *and* testing should be established. The sequence for exploration and testing in the exploratory facility should be organized around specific intermediate goals and should be consistent with scientific needs, realistic funding expectations, and the efficient management of the excavation of the underground exploratory facility.

Continuous reevaluation of the exploration and testing program as the final design of the exploratory facility progresses will provide the opportunity to fine tune the program. For example, the DOE should consider relocating some tests presently planned for the surface-based drilling program to drill sites within the exploratory facility. Tunneling provides the opportunity to locate the near-vertical faults, which have a strong and local effect on the hydrology and geochemical properties of the rock. When a fault is crossed, sampling can be undertaken across the fault and at known distances from it. The resulting data can be better related to the existing features. In some cases, this could offer an advantage over drilling long drillholes from the surface. In addition, given the slow drilling rate of the LM-300 deep dry coring drill and the long drill lengths required when drilling from the surface, shifting appropriate tests to the underground could speed program progress and reduce costs.[6]

Conclusions

1. Exploring across the geologic block to gather the data necessary for an early determination of the site's suitability for repository development is of highest priority. Exploration should be conducted across the site above, at, and below the repository level. Tunnels should intersect anticipated major faults and any major unknown structures passing through the repository block so that typical in-situ conditions in the key geologic units (including frequency of fractures) can be evaluated.

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[6] The DOE's surface-based drilling program foresees drilling approximately 40 holes to depths of 1,500 to 5,000 ft. The first hole, UZ-16, which is 1,686 ft deep, took ten months to drill.

[illegible]

Strategies for Design and Excavation of the Exploratory Facility

[illegible]

Delay competing excavation activities until completion of the portal-to-portal loop

The fastest, most economical excavation of the 26,000-ft-long portal-to-portal loop from the north portal through the main tunnel to the south portal would be to proceed without competing simultaneous excavation activities from the same portal. Multiple excavation activities from a single portal will interfere with the advance rate of the tunnel boring machine. Interruptions to machine operation should only be allowed if the need arises to gather critical, repository-relevant scientific data that would later be unrecoverable. After the machine has transited from the north to south portals (an operation that should take about 12 months), access would be available from the south portal for excavating alcoves and turnouts and to begin early testing activities. At the same time, activities supporting excavation of the exploratory facility, such as mucking,[7] could be continued from the north portal. The Board strongly supports the DOE's recent proposal to drive the portal-to-portal loop without interrupting the advance of the tunnel boring machine.

After completing the portal-to-portal loop, excavation of additional east-west tunnels, as well as the core test area, can begin using a smaller tunnel boring machine. Driving a tunnel west to the Solitario Canyon Fault zone is high priority because it would complete a full east-west traverse of the major north-south trending features. Also high priority is excavation through the Calico Hills unit directly below the proposed repository horizon. To be able to evaluate the nature of faults at different levels it would be desirable to excavate portions of the tunnel in the Calico Hills unit directly below the portal-to-portal loop. Access to the Calico Hills could be obtained from the north-south ramps (see Figure 2) or from a separate surface portal. Creating a separate portal offers the advantage of reducing the number of activities taking place off the portal-to-portal loop and reducing the possibility of adversely affecting the repository operational area. A separate portal also might allow excavation of the Calico Hills unit to be carried out as early as funding will allow.

Use rail to support tunnel boring machine operation

The Board recommends the use of rail, rather than rubber tired vehicles, to support tunnel boring machine operations. The use of rail to transport people and materials in and out of the tunnel is more efficient and cost-effective. Rail will

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[7] The removal of all excavated rock (muck) will be undertaken using a conveyer, which will transport the excavated rock out through the north portal. Conveyer operations should be devoted entirely to the support of the tunnel boring machine until completion of the portal-to-portal loop.

[illegible]

[illegible]

technical, cost, and schedule reasons why excavating smaller tunnels outside the portal-to-portal loop is preferable. Smaller diameter tunnels are more stable structurally, particularly when excavating in fault zones. Using a smaller machine outside the portal-to-portal loop will be more efficient and more cost-effective because smaller diameter tunnel boring machines advance faster through rock,[20] can be moved more rapidly from point to point, and can be used more efficiently to excavate intersections. Finally, the smaller the tunnels, the easier they are to backfill if they cannot be integrated into a potential repository.

The Board supports the DOE's decision to use a smaller machine outside the portal-to-portal loop. However, the DOE must plan now for the start of additional tunnels with at least one, perhaps two, smaller tunnel boring machines. According to the DOE schedule (DOE 1993), the new 25-ft machine should begin excavation of the portal-to-portal loop in July 1994. Based on industry standards and the DOE decision to excavate portal to portal without interruption, excavation of the portal-to-portal loop should take no more than approximately 12 months. If this schedule is met, the contractor should have the smaller tunnel boring machine on site ready to begin excavation by July 1995.

The Board is concerned that possible delays in acquiring a smaller machine could further delay the site-characterization program. Because of these potential delays and because of budget constraints in the program, the Board suggests that the DOE let the contractor acquire all future machines (equipment should be owned by the contractor). A number of options are available for obtaining a machine at much lower costs in much less time than was required for the DOE to purchase the new 25-ft machine.[21] For example, the contractor could rent, or possibly purchase, a used machine for use on the project.

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[20] Industry experience during the last few years indicates that minimum overall advance rates during tunneling should run about 100 ft per working day for a 25-ft machine and 125 ft per working day for an 18-ft machine in the welded tuff of the Topopah Spring formation. Rates in the softer nonwelded tuff of the Calico Hills formation for a 16- to 18-ft machine should average 175 ft per day. Construction risks and delays increase with increased tunnel size and include delays to install additional rock support in fault zones or other zones of low rock quality, for increased machine maintenance due to larger, less reliable components, for more frequent cutter changes (especially in hard rock), and slower production rates. Costs also increase with increasing size. Experience shows that a 25-foot tunnel costs about 1.5 times as much as an 18-foot tunnel. (See also Gertsch and Ozdemir 1991.)

[21] In a recent memorandum (NWTRB, August 1993), the Board recommended to DOE management that consideration be given to acquiring a government-owned tunnel boring machine currently parked in N-Tunnel at Rainier Mesa, Nevada, for use at nearby Yucca Mountain.

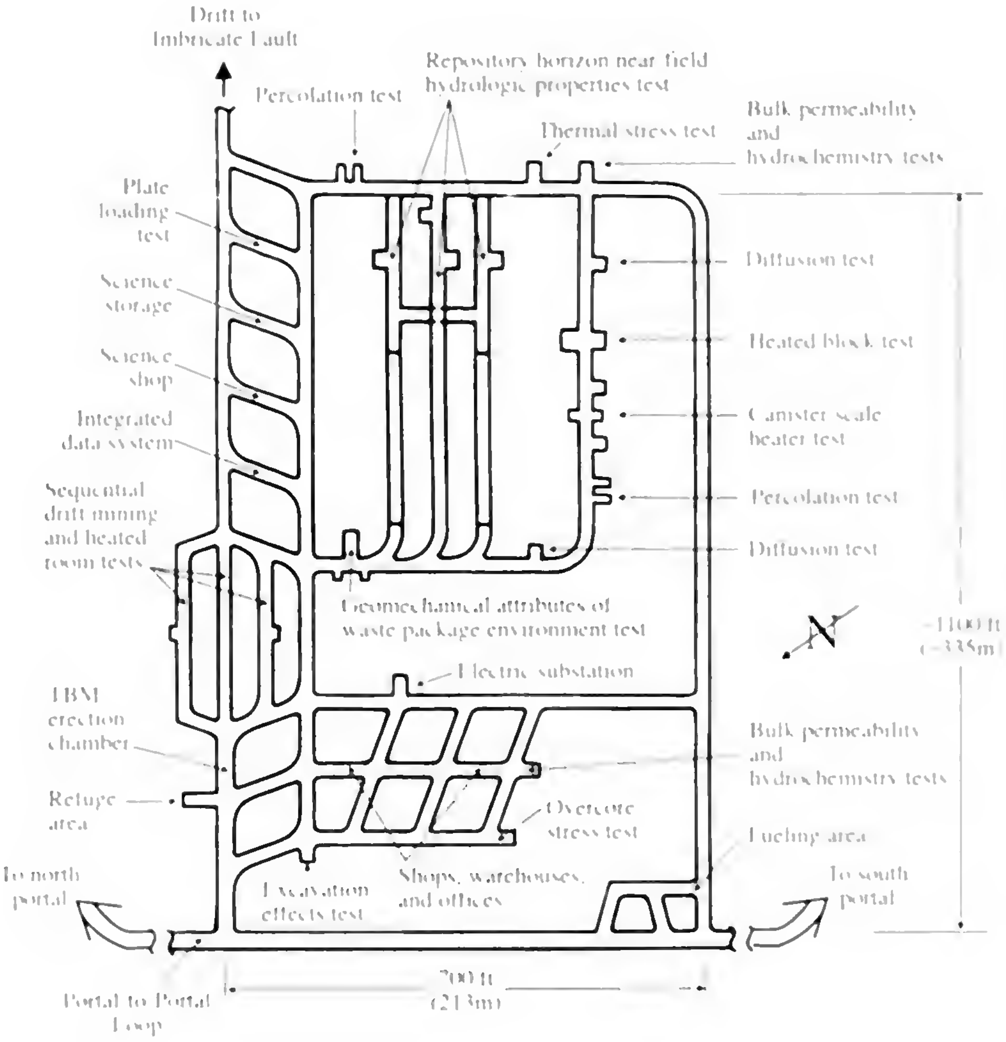
Use a tunnel boring machine to excavate the [illegible]

[illegible]

Reduce and simplify surface and subsurface [illegible]

[illegible]

Figure 3 Currently proposed core test area *(plan view)*



Source: DOE-YMSCP, Title I, *Design Summary Report*, Vol. 3, Design Drawings, September 3, 1991, Drawing No. YMP-025-2-MING-M133 (DOE 1991)

[illegible]

[illegible]

Develop possible repository designs in conjunction with [illegible] facility design

[illegible]

[illegible]

Conclusion

[illegible]

2. The use of rail, rather than rubber tired vehicles, is the most efficient and cost-effective way to support tunnel boring machine operations. Rail will allow more efficient use of tunnel space.

3. Plans are not yet under way to acquire additional smaller diameter tunnel boring machines for excavating tunnels off the portal-to-portal loop and in the core test area. Possible delays in acquiring smaller machines could further delay the site-characterization program.

4. The surface and subsurface facilities and utilities still have not been sufficiently reduced to reflect recent project changes. Once that has been accomplished, the site-characterization program can proceed more quickly and at reduced costs.

5. Conditions in the core test area, the site of critical intermediate- and long-term thermal testing, should approximate as precisely as possible conditions that will be present in a potential repository. Excavating the core test area using a full-face tunnel boring machine, rather than using drill-and-blast techniques or other high-risk excavation technologies, will create the necessary conditions.

Recommendations

The Board makes the following recommendations.

Recommendations for exploration and testing

1. Explore across the block to access the major geologic features, many of which are near vertical and north-south trending. These features should be explored above, at, and below the repository level. Any changes to this plan should result from sound analysis of site-characterization issues.

2. The DOE should reinitiate its underground thermal testing program as soon as possible to allow the development of instrumentation and procedures and to gain as much testing experience as possible *prior* to initiating testing in the core test area. Given the potential for continuing program delays — including delays in excavating the core test area — development of an underground testing facility (outside the core test area) may prove very timely and cost-effective.

[illegible] for exploration and [illegible] intermediate [illegible] and [illegible] and with [illegible] of exploration and [illegible] underground facility based [illegible] the industry.

Recommendations for design and excavation

The DOE [illegible] schedule for the [illegible] one smaller tunnel boring machine [illegible] as soon as the portal to portal loop [illegible] than the DOE should [illegible]

Surface and subsurface facilities [illegible] to reflect the new excavation [illegible] should be simplified so that [illegible] facilities.

Management at the Project Level

The Board recognizes the complex regulatory and oversight constraints facing the U.S. high-level waste management program in general and the challenges inherent in managing this large scientific and engineering project in particular. However, most of the construction activities required to develop the exploratory facility are well within the experience of the underground construction industry.[25] Tunnel support and excavation conditions are not particularly extreme as compared to other underground projects, and technology for rapid and safe excavation and tunnel support are well developed. The Board believes a wealth of expertise and experience exists from which the DOE could draw — even for this first-of-a-kind facility.

Project Decisions

The Board has found that important project decisions often do not reflect what would be considered standard practice in the underground construction industry. Three areas where improvements would make the project more efficient are discussed briefly below.

1. Contracting practices for the project are not typical of the industry and do not encourage competition or innovation. According to the DOE, a cost-plus award-fee contract was chosen for the exploratory facility because construction goals are subject to being overridden by scientific and technical needs. However, the Board remains unconvinced that a cost-plus award-fee contract is the best type of contract to be used for the design and construction of the exploratory facility.[26] The standard industry contract is the firm fixed-price contract, which is open to competition and awarded to the lowest bidder. It is the most common type of contract used because it provides the greatest performance incentives to the contractor.

To help control the cost and time required for exploratory facility construction, the DOE should develop cost and schedule incentives for current contracts. The Board also suggests that the DOE consider using conventional fixed-price or cost plus incentive fee contracts on future portions of the exploratory facility.[27]

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[25] *Underground construction industry* refers to those who participate in the construction of permanent underground facilities (e.g., hydroelectric, public transportation, public water systems).

[26] Questions also have been raised by DOE Assistant Secretary Thomas P. Grumbly about the efficiency of the DOE's award fee contracts (*Energy Daily*, Monday, July 19, 1993).

[27] This type of contract could be used, for example, for the excavation of accesses and the traverse of the Calico Hills, especially if exploration is conducted from a separate portal or during the construction of a prototype thermal test facility.

engineering practices used in the industry, time and cost savings could be realized that could help minimize potential delays and free money for important scientific and technical activities.

To take advantage of this existing experience, the DOE should establish as soon as possible a geoengineering board, which would work with the technical and management staff and report to Yucca Mountain project management. Large underground construction projects, such as subway systems, the superconducting super collider, and hydroelectric facilities, use such geoengineering boards. These boards are typically composed of four-to-seven members with expertise in engineering, construction, and management of large underground projects. Such a geoengineering board could meet regularly with Yucca Mountain Project management, staff, and contractors to review detailed decisions early on — *when they are first being made*. Potential members should be nationally recognized and be selected based on experience serving on similar boards for projects of commensurate complexity.[31]

The DOE does at times use technical review panels. However, these technical reviewers traditionally are employed by the DOE or firms that are under contract to the DOE, and they often lack adequate experience on tunneling projects of similar complexity. For example, at the recent 90 percent design review, of 41 review team members, all were employees of the DOE or under contract to the DOE on this program,[32] and few had experience on projects using tunnel boring machines. As a result, issues such as those mentioned above, which could easily have been resolved early in the design stage by a geoengineering board, were still being evaluated during the 90 percent design review.

Organizational Structure and Management at the Project Level

As the Board stated in its *Special Report*, the overall civilian radioactive waste management program (OCRWM) is large and diffuse, and specific responsibilities are unclear. This also is true at the Yucca Mountain project level where numerous contractor groups have been hired to perform engineering and construction tasks. As of November 30, 1992, employees from 24 organizations were working on the project.[33] Multiple levels of management are involved in decision making, and responsibilities are unclear.

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[31] Because of the breadth of its mission and reporting mandate, the NWTRB is not equipped to carry out the detailed review that would be asked of such a geoengineering board.

[32] Presentation at the DOE's 90 Percent Design Review, July 19, 1993 (TRW 1993).

[33] More than 1236.7 full time equivalent contract employees (DOE 1992).

Conclusions

1. As many have noted, a high percentage of funds have been allocated to maintain a large overhead and infrastructure. This has left relatively limited amounts for site-exploration and testing activities. The DOE cited insufficient funds as the reason for terminating underground thermal testing in 1989 and for the delay of the design and construction activities for the exploratory facility in 1992. Although underground work has begun, if the DOE does not allocate more funding to the exploration and testing program, the delays will likely continue.

2. Contracting and purchasing practices established by the DOE do not contain incentives for cost-effective and timely performance of contractors.

3. Project management is diffuse, and the decision-making process involves many different contractor organizations, multiple levels of management, and unclear accountability.

Recommendations

1. Consistent with practices in the underground construction industry, the DOE should establish a geoengineering board with four-to-seven members who have expertise in the engineering, construction, and management of large underground projects. Members should be nationally recognized and be selected based on their previous experience serving on similar boards. Such a geoengineering board would meet regularly with Yucca Mountain project management, staff, and contractors to review detailed decisions early on — as they are being made and to provide guidance on improving the management of the design and excavation of the exploratory facility.

2. The DOE should develop a more efficient system for managing the exploratory facility design and construction that contains greater accountability and incentives for cost-effective and timely performance of the contractors.

3. The Secretary of Energy's review of the financial aspects of the civilian radioactive waste management program should include an evaluation of the program's funding allocation decisions. This review should help find ways to maximize the funds that are being made available for scientific studies and to ensure that the momentum of the exploration and testing program under way at Yucca Mountain is maintained.

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