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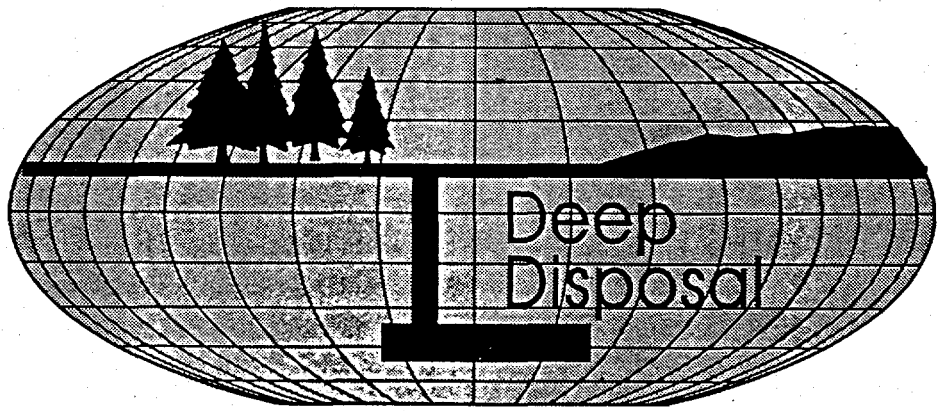

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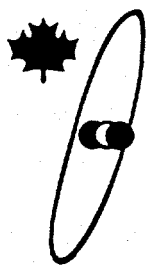

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SEQUENTIAL EVALUATION OF THE POTENTIAL GEOLOGIC REPOSITORY SITE AT YUCCA MOUNTAIN, NEVADA, U.S.A.

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ABSTRACT

1996 will be remembered as a year of transition, even upheaval, for the United States' program for geologic disposal of spent reactor fuel and high-level nuclear wastes from military reprocessing. The 1996 budget for the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) combined with reduced funding levels anticipated through the end of the decade make it necessary to substantially modify the United States' waste management program. The two major changes DOE has made in response to the 1996 budget involve, 1) resequencing the technical and statutory milestones for Yucca Mountain characterization, and 2) terminating further development of most waste acceptance activities, multi-purpose canister development, and generic transportation work. Budget reductions combine with legislation now before the 104th U.S. Congress that, if it is signed into law, would redirect the program to authorize temporary storage of waste at an interim storage facility and de-emphasize long-term disposal and isolation. This paper explains the changes that are being planned for the characterization program at Yucca Mountain.

Yucca Mountain, Nevada, is the only site being studied in the United States for a geologic repository: an arid terrane of 12 million-year-old unsaturated, stratiform volcanic tuff. Funding for the site characterization program at Yucca Mountain for 1996 was cut by roughly one half from that anticipated in 1994 as needed to complete three major milestones by 2001. These project milestones included, 1) a time-phased determination of Site Suitability, and if a positive finding, 2) completion of an Environmental Impact Statement, and 3) preparation of a License Application to the U.S. Nuclear Regulatory Commission (NRC) to authorize repository construction. In reaction, the Yucca Mountain Site Characterization Project has shifted from parallel development of these milestones to a sequenced approach with the Site Suitability Evaluation being replaced with a management assessment, and completion of an EIS and LA being de-emphasized until the beginning of the next decade.

Changes to the regulatory structure for the disposal program are under consideration by DOE (its siting guidelines) and the NRC (repository regulation). The possibility for NRC and DOE to develop a site-specific regulatory structure follows from the National Energy Policy Act of 1992 that authorized the U.S. Environmental Protection Agency to develop a site-specific environmental standard for Yucca Mountain.

INTRODUCTION

The 1996 fiscal year (Oct. through Sept.) budget for the U.S. Department of Energy's (DOE) high-level waste management program is approximately $315 million dollars, roughly one half that expected to complete significant technical and programmatic milestones enabling the DOE to prepare a License Application for repository construction in 2001. The 1996 appropriation accompanies clear indication from the U.S. Congress that funding levels anticipated by the program when a Site Characterization Plan (SCP)[1] was written for the Yucca Mountain site in 1988, will not be realized. This change in funding expectations serves as impetus for DOE to, 1) replan the site characterization program to bring it to conclusion, 2) rethink what standard of proof the geological sciences can deliver to the managers and agencies charged with determining whether or not a repository will be built at Yucca Mountain, and 3) acknowledge that ultimately less information with higher levels of uncertainty will be available for a siting decision. To meet the milestones identified in the Nuclear Waste Policy Act (NWPA) of 1982, as amended in 1987, the DOE's Yucca Mountain Site Characterization Project has resequenced development of major technical products that had been under parallel development since 1988.

The Clinton Administration's 1996 fiscal year request for the U.S. Department of Energy's (DOE) Office of Civilian Radioactive Waste Management (OCRWM) was $630 million. That part destined for the Yucca Mountain Site Characterization Project (geologic studies, underground Exploratory Studies Facility (ESF) design and construction, and waste package design) was $472 million. In November 1995, the President signed a $400 million appropriation for all work conducted by OCRWM in fiscal year 1996. The appropriation bill designated $250 million specifically for Yucca Mountain site characterization.

In addition to the reduced funding in 1996, authorizing legislation now resides in House and Senate committees in the 104th Congress to amend or replace the NWPA, as amended in 1987 to focus site characterization at Yucca Mountain. These new legislative changes would redirect the United States' program to emphasize temporary interim storage and the infrastructure needed to transport nuclear waste, and de-emphasize disposal. At the same time, it alters the emphasis for OCRWM funding toward engineering and away from the scientific and geologic disciplines. The appropriation bill withheld, or "fenced off", $85 million from access by OCRWM until a temporary storage site for spent fuel was designated for the nation, thus the total 1996 appropriation of $315 million.

There are two plausible scenarios for Yucca Mountain funding between now and the end of the decade; levels that are, 1) close to the FY 1996 appropriation (no interim storage site designated), and 2) declining each year from the FY 1996 level (an interim storage site is designated) (Figure 1). Both scenarios exhibit much lower funding levels than the program had anticipated in a 1994 Program Plan[2], itself a major replan of the program of studies envisioned in the Yucca Mountain SCP. The 1994 Program Plan defined the logic designed to complete the 106 studies in the SCP and make a Site Suitability Evaluation, compile an Environmental Impact Statement (EIS) in 1998, and, if the Site Suitability Evaluation was positive, a License Application (LA) for the U.S. Nuclear Regulatory Commission (NRC) to acquire a license to construct a repository. For a Site Suitability finding, a sequential evaluation of individual technical qualifying conditions

from DOE's siting guidelines was scheduled. The guidelines are attributes of the geologic system that are evaluated in combination with repository design, to arrive at a finding whether or not a repository system could be built feasibly and would be safe. These technical findings were to be time-phased through 1998 as site characterization data became available. The individual technical findings would sum, if positive, to a Site Suitability finding in 1998.

In reaction to anticipated funding levels, the Yucca Mountain Site Characterization Project has shifted from parallel development of an EIS, the time-phased technical evaluations envisioned for Site Suitability, and the preparations for writing a LA; to sequential development of these milestones. The time-phased Site Suitability Evaluation is to be replaced with a management assessment, and completion of an EIS and LA are deferred.

MANAGEMENT ASSESSMENT IN 1998

A very different geologic disposal program is now being planned to conform to the very austere budget environment OCRWM now anticipates. Central to this new program is a management assessment in 1998, the major accomplishment for OCRWM this decade. The management assessment will provide a DOE evaluation and judgement to the U.S. Congress about the likelihood for success in the regulatory evaluation that is to follow, and costs to complete this evaluation. The assessment will report to the nation,

1) what type of a repository can be built at Yucca Mountain and what capacity is permitted,

   - a package of specific design work on the critical elements of the repository and the waste package, including a concept of operations that identifies available technologies to accomplish the objectives of geologic disposal.

2) how it will perform,

   - an analysis of total system performance, based upon repository and waste package design elements and available data, which will describe the probable behavior of the repository.

3) a plan and cost estimate for work remaining to complete a License Application, and

4) how much a repository system will cost to build and operate.

Total System Performance Assessment

The unifying and driving geotechnical activity for the management assessment involves Total System Performance Assessment (TSPA) modeling and maturation of the mathematical process models that abstract natural processes important to understanding how the site will isolate waste over time. The assessment will need designs for a repository and waste package sufficient to make a cost estimate for the system. Iterative TSPAs were performed for Yucca Mountain in 1991 and 1993 and the most recent TSPA was completed

in 1995[3]. It evaluated the performance of the repository without incorporating the effects of disruptive events such as igneous activity and fault displacement. The earlier TSPA exercises showed that these disruptive scenarios do not appreciably affect the performance of the site.

Because the U.S. Environmental Protection Agency will revise the repository safety standard in the coming year, and because DOE may have to consider isolation periods beyond 10,000 years, two system-level performance measures were evaluated in TSPA 1995, 1) cumulative radionuclide releases from the repository were calculated for 10,000 years, and 2) the peak doses resulting from radionuclide releases over hundreds of thousands of years. The results indicate that the engineered barriers could provide containment and contribute to waste isolation for extended periods. The results also indicate that the natural system by itself, under certain assumptions, can contribute to isolation of the radionuclides for a very long period. The analyses tend to confirm the importance of the rate and distribution of ground-water movement to the performance of the natural system. A combination of waste package and performance of the natural system contribute to containing and isolating radioactive wastes within the Yucca Mountain area for some tens to even hundreds of thousands of years. When the period of concern is extended up to 1 million years, only a few factors dominate the calculated response and only a few long-lived radionuclides contribute significantly to this response. TSPA 1995 results indicate that the very long-term peak release rate and the peak dose are affected predominately by dispersion and dilution processes.

The DOE's 1998 management assessment will be based on an updated performance assessment that relies more directly on the process-level models now being developed for the site and engineered system. A more sophisticated biosphere model is also expected to be in place to allow calculation of dose and the associated risk to a representative individual in an affected population.

The TSPA for the management assessment will reflect the site and engineered system process-level understanding using data available at that time, and it will represent DOE's best estimate of system performance. Since TSPA 1995 used site and design information that is not expected to change substantively, or change in a way detrimental to site performance, the results of TSPA for the management assessment will likely indicate better performance, with lower releases and doses than the 1995 analysis. Lower; but not by "orders of magnitude". At the conclusion of site characterization, uncertainties will continue to exist in the knowledge base for both engineered components and natural system processes. These uncertainties will be reflected in the alternate conceptual models and parameter distributions that are considered in TSPA modeling analyses and the subsystem models used to support TSPA.

The resources to be made available to DOE will not allow all technical issues about the site to be resolved prior to the 1998 management assessment, nor is it practical to do so. Using the insights developed from iterative performance assessments, the technical uncertainties contained in the 1988 SCP can now be shown to be not equally important because the individual elements of the disposal systems expected to be deployed are better developed and more quantitative. During the next few years, the TSPA and supporting physical process models will identify the most important uncertainties and accommodate

parameter variation so that occurrence probabilities for phenomena and consequence evaluations can be bounded.

With a completed management assessment that is favorable, the U.S. Congress will have a clear idea for what lies ahead, along with the associated costs. The program would be poised to proceed to licensing with a defensible set of data and analyses to address the U.S. Nuclear Regulatory Commission's (NRC) requirements.

Site Characterization Program/Waste Containment and Isolation Strategy

The 1998 Site Characterization Plan (SCP) contained a testing philosophy that was very conservative and low risk. The SCP was underpinned by an expectation that if the 106 component studies it contained were completed, likelihood would be high that DOE would have the data needed to write a License Application that the NRC could act upon. The SCP did not attempt to weigh which studies were more important than others to evaluate site performance. Those insights were not then known. Over a period of years, interactions with the NRC, oversight bodies, and public interest groups have taken place where DOE has explained the planning basis for site characterization. Expectations have built that DOE would be able, and be required, to present site characterization data, analyses, and conclusions from a knowledge base that would ensure high confidence levels in all conclusions, and low levels of uncertainty in these conclusions. Anticipated lower funding levels have only hastened a reassessment about what standard of proof geologic studies can provide to a licensing arena given, 1) earth sciences' epistemological limitations, 2) resource limitations that constrain options for continued characterization work, and 3) that a performance confirmation program will be in place years before a future license amendment would be sought to allow receipt and possession of nuclear materials for emplacement in a repository.

In order to focus the remaining testing program on the most important issues, DOE is documenting a waste containment and isolation strategy for Yucca Mountain. This strategy identifies hypotheses about the expected interactions or behavior of engineered barrier and natural systems on containment and long-term isolation. The essence of this strategy articulates specific working hypotheses as testable bases for assessing how a waste isolation system at Yucca Mountain will perform. These hypotheses were developed based on the information collected from site characterization over the last decade and may need further verification; some more than others. The working hypotheses relate to, 1) specific hydrologic attributes of the natural system, 2) specific physical characteristics of materials that may be part of the engineered system, and 3) the important interactions between the natural and engineered systems, so that engineered enhancements can be defined that provide a defense-in-depth, or multiple safeguards, that a repository's waste isolation capability is maximized.

The strategy focuses on two technical objectives: 1) provide total containment of the waste within the emplaced waste packages for thousands of years, during the highest activity period of the radionuclide inventory and the highest temperatures, and 2) limit the annual dose to members of the general public following permanent closure of a repository.

Taken separately, the hypotheses provide the bases for organizing and explaining the rationale for additional site characterization work that is still needed. Taken together, the hypotheses comprise a structure for the assessment of the waste isolation capability of a repository at Yucca Mountain. Site characterization field work and underground testing continues to confirm that the natural system at the site contributes significantly to waste isolation. The containment and isolation strategy enables DOE to focus a more limited testing program to answer questions about a small number of specific hypotheses that may be crucial to system performance and to the 1998 management assessment:

- low infiltration allows very little water to reach the repository layer
- seepage of water into tunnels will be a small fraction of flow in the repository layer
- humidity near the waste packages will be low for thousands of years
- waste package corrosion rates will be negligible at low humidity
- the outer barrier of the waste package will provide corrosion protection for the inner barrier for thousands of years
- backfill, if included in the repository design, will limit radionuclide transport
- groundwater flow in the saturated zone under the repository is large compared to the flow that may contact the waste
- water percolating downward in the vadose zone is mixed and diluted in the saturated zone

Only a few surface-based tests are planned for fiscal year 1996. Those tests that are conducted will focus on hypotheses identified in the waste containment and isolation strategy, including testing with reactive tracers to characterize flow in the saturated zone. Monitoring of seismicity, meteorological conditions, pneumatic pathways of air movement through fractures and pores in the unsaturated tuffs, and unsaturated zone hydrology will be continued.

Attention continues to be focused on the synthesis, analysis, and documentation of the substantial amount of data collected to date. Key models of natural processes will be documented and available by the end of fiscal year 1996. This documentation will provide input for the design work and for the next TSPA iteration that supports DOE's management assessment.

EXPLORATORY STUDIES FACILITY

DOE's tunnel boring machine (TBM) operations have significantly exceeded expectations. The TBM, called the "Yucca Mucker", was well ahead of schedule through most of 1995. In early April 1996 the TBM had penetrated over 5 km into the mountain (Figures 2 and 3). Design activities and construction of the Exploratory Studies Facility (ESF) will continue during 1996, and underground testing will continue apace with construction. The Ghost Dance Fault (Figure 3) is expected to be accessed by spring 1996 to allow testing for water and air movement through a faulted zone of unsaturated volcanic rock.

Progress excavating the ESF has permitted project scientists to begin direct observation and testing of subsurface geologic and hydrologic conditions in the potential repository layer of welded volcanic tuff (Topopah Spring Tuff), as well as in the welded and

non-welded tuff layers overlying it. Studies also proceed on the engineering properties of the rock, and its response to construction activities. Four alcoves have been constructed to measure air and water movement along faults and tuffaceous geologic contacts. A thermal testing alcove is under construction for phased implementation of short and long, single and room-scale heater tests. No water has been observed dripping or flowing into the excavation, even in fractured or faulted zones, nor have perched water zones been encountered. This is consistent with DOE's hypothesis regarding the character of ground-water flow in the unsaturated rock at Yucca Mountain. No unexpected features, such as major new faults have been observed, but some postulated geologic structures mapped at the surface have been found to be absent underground.

POTENTIAL REGULATORY CHANGES

The possibility of developing a site-specific regulatory structure for Yucca Mountain to account for knowledge acquired since the United States developed a generic regulatory structure in the mid-1980s is at hand. It follows from the National Energy Policy Act of 1992 that authorized the U.S. Environmental Protection Agency (EPA) to develop a site-specific environmental standard for Yucca Mountain. U.S. Nuclear Regulatory Commission is considering development of a new site-specific regulation for Yucca Mountain to coincide with EPA's new standard, and DOE is considering changes to its siting guidelines to adapt them to this specific-site.

SUMMARY

In 1996 the United States' high-level nuclear waste program experienced the biggest change since 1982 when authorizing legislation for geologic disposal was passed. An expectation that funding levels would be adequate to accomplish parallel completion of a Site Suitability Evaluation, an Environmental Impact Statement, and preparatory work for a License Application has underpinned the DOE's disposal program since the Nuclear Waste Policy Act was amended in 1987 and a Site Characterization Plan for Yucca Mountain was written in 1988. To meet the challenge posed by much lower funding levels that will not sustain parallel development of statutory milestones, planning assumptions and expectations that evolved over the last decade will need to change. DOE has moved toward accommodating these changes by planning sequential development of the project's major milestone products. Decision-makers early in the next decade will need to rethink expectations for what information will be available, and anticipate higher uncertainties in the geotechnical conclusions that are reached.

A management assessment replaces a time-phased Site Suitability Evaluation process. At the conclusion of site characterization in 1998 DOE intends to report, 1) what type of a repository can be built at Yucca Mountain and what capacity is permitted, 2) how it will perform, 3) designs for a repository and waste package adequate to gauge how much a repository system will cost to build and operate, and 4) the costs for additional data or analyses needed for licensing and a plan to acquire them. If the 1998 management assessment proves favorable and the nation decides to pursue further development of a geologic repository system, the program will move to a regulatory review stage and

complete the next sequence of milestones, an Environmental Impact Statement and a License Application to authorize construction of a repository.

Existing site study programs from the 1988 Site Characterization Plan are concluding, and only limited new work will be carried out in 1996. Most activity in the next three years will be directed toward archiving past work, synthesizing data, and documenting results. The Tunnel Boring Machine continues to excavate the Exploratory Studies Facility and underground testing proceeds apace with excavation. Current plans are to surface, or "daylight", the TBM at the South Portal Ramp within the next 6 months.

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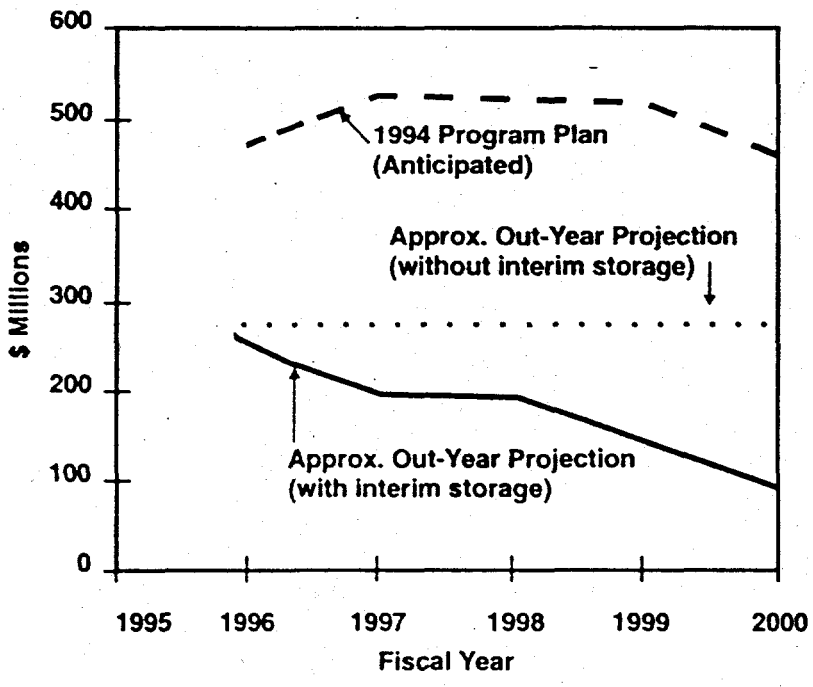

Figure 1. Graph showing funding profiles for the Yucca Mountain Site Characterization Project; 1) anticipated from the 1994 Program Plan for a License Application in 2001, 2) possible funding profile if interim storage is authorized, and 3) possible funding profile if interim storage is not authorized.

Figure 2. North Ramp of the Yucca Mountain Exploratory Studies Facility at the southward turn, approximately 2.5 km into the mountain.

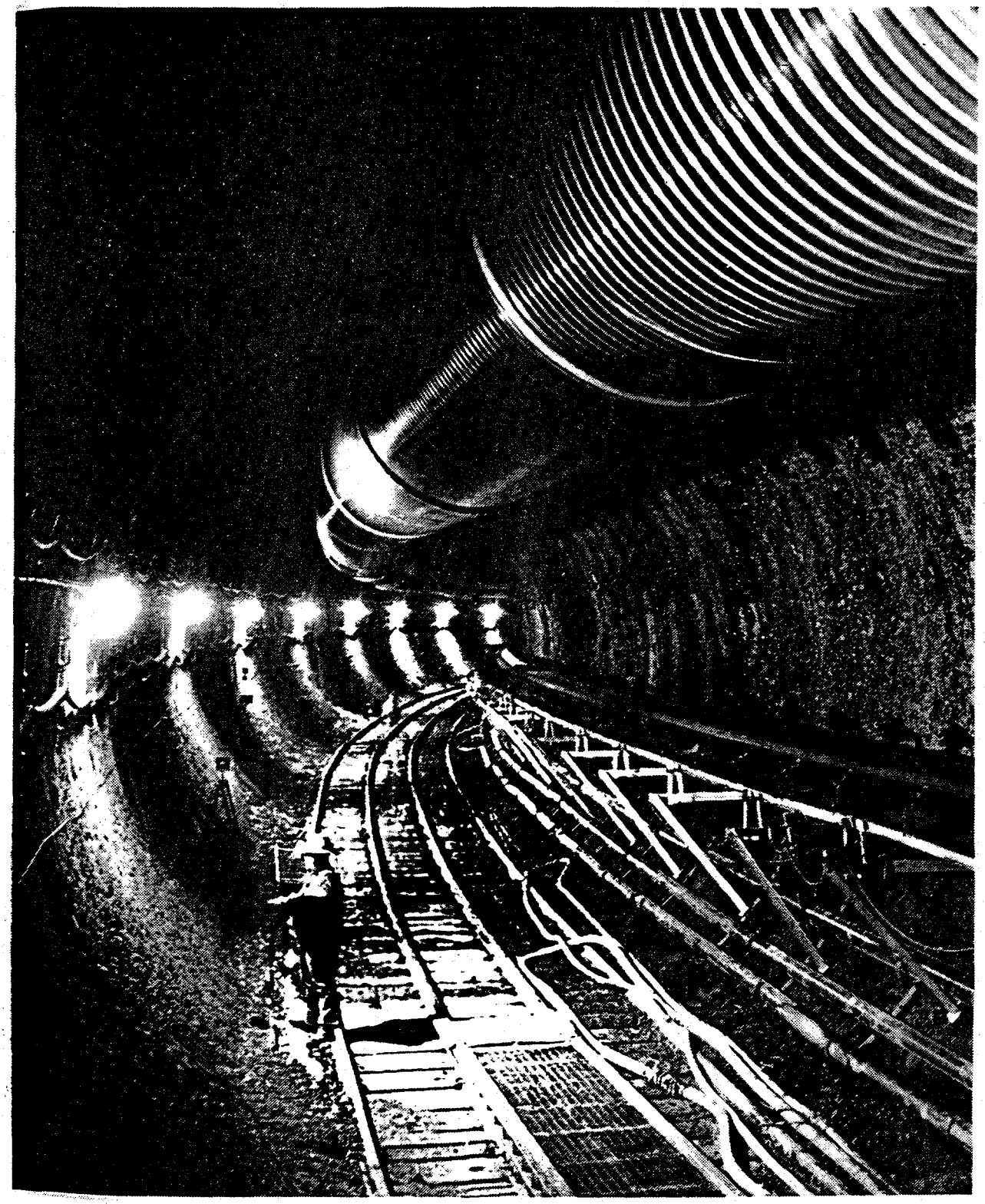

Figure 3. Planimetric view of the Exploratory Studies Facility (ESF) showing anticipated vs. actual progress excavating an 8-km long, 7.6 m-diameter tunnel. Excavation of the starter tunnel to receive the Tunnel Boring Machine (TBM) began at the North Portal in April 1993. TBM assembly and phased operational testing took place throughout 1994. The TBM began continuous mining in December 1994. The tunnel proceeds eastward from the North Portal located in Midway Valley at a 2 percent grade to the depth of the potential welded tuff layer under study (about 300 m beneath the crest of Yucca Mountain). In October 1995 the TBM passed into the prospective welded volcanic tuff (Topopah Spring Tuff) layer being examined for a potential repository. In 1995 the TBM routinely achieved penetration rates between 25 and 50 meters per day, was well ahead of schedule, and penetrated about 5 km into the mountain as of early April 1996. The underground halfway point was passed in February 1996 and excavation will proceed south within the repository layer and then westward to "daylight" at the South Portal during late 1996 or early 1997. Four test alcoves have been constructed (either drill and blast or mobile miner) for pneumatic and hydrologic testing of unsaturated geologic layers or contacts (Alcoves 1, 3, and 4) or faults (Alcove 2). Excavation has begun on the thermal test alcove for long-term heater testing of single and room-scale emplacement configurations and an alcove to test hydrologic properties of the Ghost Dance Fault. No unexpected geologic conditions or structural features, such as dripping water, perched water zones, or major new faults have been observed. Postulated geologic structures mapped at the surface have been found to be absent underground, however.