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SANDIA REPORT SAND84–1003 • Unlimited Release • UC–70
Printed August 1984

NNWSI Exploratory Shaft Site and Construction Method Recommendation Report

Sharla G. Bertram

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-AC04-76DP00789

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America
Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A06
Microfiche copy: A01

Distribution
Category UC-70

SAND84-1003
Unlimited Release
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NNWSI EXPLORATORY SHAFT SITE AND CONSTRUCTION METHOD RECOMMENDATION REPORT

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ABSTRACT

This report documents the process by which alternative construction methods were evaluated and by which potential sites were screened by the Nevada Nuclear Waste Storage Investigations (NNWSI) project for the exploratory shaft at Yucca Mountain, in Nye County, Nevada. The evaluation was made by the Ad Hoc Technical Overview Contractor Committee. Our recommendations were to construct a vertical shaft using conventional mining techniques in a dry canyon known as Coyote Wash, located on the east flank of the mountain.

ACKNOWLEDGMENTS

The bases for this report are the working papers resulting from the deliberations of the Ad Hoc Technical Overview Contractor (TOC) Committee, which were compiled by the Committee's chairpersons. The contributions to the working papers of the individual Committee members, who were essential to the evaluation process, should be recognized. The Committee membership, their organizational affiliations and functions are listed below.

S. G. Bertram. Chair. Sandia National Laboratories (SNL)-TOC. Environment. Also chaired Ad Hoc Working Group (AHWG).

A. E. Stephenson. Chair. SNL-TOC. Facilitator.

C. W. Myers. Los Alamos National Laboratory (LANL). Exploratory Shaft (ES) Test Design. Also on AHWG.

D. C. Nelson. LANL. ES Design. Also on AHWG.

T. J. Merson. LANL. ES Design (Alternate).

J. Robison. U.S. Geological Survey (USGS). Hydrology.

R. Spengler. USGS. Geology.

L. W. Scully. SNL. Repository Design. Also on AHWG.

J. A. Milloy. SNL. Repository Design (Alternate).

S. Francis. LANL. Advisor.

J. N. Fiore. U.S. Department of Energy, Nevada Operations. Advisor.

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EXECUTIVE SUMMARY

This report documents the process by which alternative construction methods were evaluated and potential sites were screened for the Exploratory Shaft (ES) at Yucca Mountain, in Nye County, Nevada. The evaluation was made by the Ad Hoc Technical Overview Contractor (TOC) Committee during the months of April, May, and June, 1982. The Committee used a decision-tree analysis technique called the Figure of Merit (FOM) to evaluate both the construction methods and the sites. The organization of this summary parallels the organization of the report, with the discussion of the construction method evaluation followed by site screening. The Committee's recommendations were submitted to the Nevada Nuclear Waste Storage Investigations (NNWSI) Technical Integration Group (TIG).

Construction Recommendations

Twelve construction alternatives were considered. Of these, five were evaluated using the FOM technique. Three of these five considered constructing an ~1800 ft shaft in the unsaturated zone of the Yucca Mountain volcanic tuff deposits. These three alternatives would characterize the unsaturated Topopah Springs and Calico Hills units. The remaining two considered constructing an ~3500 ft shaft into the zone of saturated tuffs below the water table to characterize the Bullfrog and Tram units.

The unsaturated zone alternatives were: C1 - drill a vertical shaft; C2 - mine a vertical shaft; or C3 - mine a declined shaft. The saturated zone alternatives were: C4 - mine a vertical shaft or C5 - drill a vertical shaft. The deeper shafts would be mined or drilled to full depth before characterization.

Criteria were established for evaluating the construction alternatives. Five categories of criteria were developed: Site Characterization, Shaft Constructibility, Cost and Schedule, Environment, and Health and Safety.

Site Characterization Criteria--These criteria considered whether 1) Rock characteristics along the shaft face could be examined; 2) Flow rates of water in the rock could be detected and measured; 3) Multiple horizons could be accessed; 4) Appropriate rock samples and uncontaminated water samples could be obtained; 5) Rock damage along the shaft face could be minimized; and 6) Effects on the rock formations of construction fluids could be minimized.

Shaft Constructibility Criteria--These criteria considered whether 1) Adverse geologic and hydrologic problems could be controlled; 2) Unexpected adverse conditions or modification of the exploration approach could be accommodated; 3) Verticality (where applicable) could be maintained along with flexibility and diameter selection ability; 4) Experienced contractors were available; and 5) Enlargement beyond the intended diameter could be minimized.

Cost and Schedule Criteria--These criteria considered 1) The relative time to perform the construction including lead time; 2) The relative cost of the construction and supporting equipment; 3) The availability of equipment; and 4) Contractor availability.

Environmental Criteria--These criteria considered 1) The difficulty of restoring disturbed surface areas; 2) The total surface area disturbed; 3) The difficulty of control and relative hazard of effluents; and 4) The ability to control airborne emissions and dust to acceptable levels.

Health and Safety Criteria--These criteria considered 1) The relative industrial hazards and the ability to follow the requirements of NTS procedures and regulatory standards; and 2) The relative comfort and convenience of workers.

The relative performance of each alternative for each criterion was estimated and merit values were computed. The merit values of the construction alternatives are given in Table 1. The FOMs, found by adding the merit values, were the basis of the Committee's recommendation to the TOC and the TIG. The unsaturated zone was not compared to the saturated zone; the FOMs of the last two alternatives are relative only to each other.

The Figures of Merit show a preference for constructing a conventionally mined, vertical shaft, either into the unsaturated or the saturated zone (Alternatives C2 and C4). The alternative

Table 1. Figures of Merit for Exploratory Shaft Construction Method Recommendation

CRITERIA	Max	C1*	C2	C3	C4	C5
		MERIT VALUES				
		Unsaturated			Saturated	
1. Site Characterization	2.25	0.74	2.18	2.16	2.18	0.78
2. Constructibility	1.50	0.70	1.25	1.00	1.21	0.74
3. Cost and Schedule	0.75	0.59	0.56	0.27	0.47	0.60
4. Environment	0.25	0.17	0.15	0.11	0.15	0.17
5. Health and Safety	0.25	0.25	0.10	0.15	0.07	0.22
FIGURES OF MERIT	5.00	2.45	4.24	3.69	4.08	2.51

*C1: drill a vertical shaft; C2: mine a vertical shaft; C3: mine a declined shaft; C4: mine a vertical shaft; C5: drill a vertical shaft.

of mining a declined shaft (C3) was rated as high for site characterization and higher for health and safety, but lower for constructibility. The decline was rated higher than drilling a vertical shaft (C1 and C5) for site characterization and constructibility, but the decline was considered the most costly alternative in terms of time and money. C3 was intermediate between drilling and mining a vertical shaft for health and safety. Mining a vertical shaft was considered far superior to drilling for site characterization and constructibility. The five alternatives were ranked nearly equal for environmental concerns with C3 the least favorable.

The Committee unanimously recommended mining a vertical shaft. However, the Committee also recommended that if new water in-flow data became available before initiation of mining into the saturated zone, the mining alternative should be reevaluated.

In its subsequent evaluation of the Committee's recommendation, the Department of Energy placed considerably more emphasis on the consideration of health and safety during construction. Even with an increased emphasis on this factor, mining remained the preferred construction method.

Site Selection

After submitting the construction method recommendation to the TIG, the Committee turned its attention to site selection. Four categories of criteria for evaluating surface and subsurface features were developed: 1) Scientific, 2) Engineering, 3) Environmental, and 4) Nontechnical.

Scientific Criteria--This criteria considered whether:

1) The ES would be located in favorable rock conditions;
2) The ES would access thick target units, giving priority to the unsaturated zone;
3) Some potentially adverse structures could be explored by horizontal drilling at depth, even though the ES subsurface facilities could not be placed within 100 ft of such structures; and

4) The volume to be explored would be maximized.

Engineering Criteria--This criteria considered:

1) The ability to construct the shaft;
2) Whether the construction would be done economically and with low risk of construction problems; and
3) Whether the ES could be incorporated into the repository with minimum adverse impact on repository design.

Environmental Criteria--This criteria addressed:

1) Avoiding destruction of significant archaeological resources;
2) Limiting the impact on sensitive biota to mitigable levels;
3) Containing or controlling effluents and emissions to acceptable levels; and
4) Reclaiming disturbed areas.

Non-Technical Criteria--These criteria addressed land use constraints, pollution control regulations, archaeological salvage regulations, and NTS security requirements.

Five preferred areas were identified by screening the mountain using a subset of the FOM siting criteria. All five preferred areas were considered suitable for the ES site. Two areas were located on top of the mountain ridge and three were located at the bottom of dry washes on the eastern flank of the mountain.

The five exploratory shaft sites were identified and an on-site evaluation of their surface characteristics was conducted. The criteria were then reviewed, subcriteria which could discriminate between the sites were defined, and weighting factors were developed. Nondiscriminating criteria were omitted. The relative performance of each site for each subcriterion was determined and a merit value computed. Table 2 shows the merit values for the Scientific, Engineering, and Environmental criteria and the cumulative Figure of Merit for each.

Table 2. Figures of Merit for Exploratory Shaft Site Recommendation

		MERIT VALUES				
CRITERIA	Max	S1	S2	S3	S4	S5
1. Scientific	2.75	0.91	1.48	1.81	2.19	2.38
2. Engineering	1.50	1.00	0.90	1.14	1.26	0.69
3. Environmental	0.75	0.30	0.21	0.59	0.58	0.29
FIGURES OF MERIT	5.00	2.21	2.59	3.54	4.03	3.36

The Figures of Merit show why the Committee unanimously recommended Site 4, located in Coyote Wash. Site 5 rated slightly higher than Site 4 scientifically, but significantly lower in the engineering and environmental considerations. Site 3 rated as well as Site 4 environmentally and was a close second for engineering, but was less valuable scientifically. Sites 1 and 2, located on the ridge top, were of lower value than the wash-bottom sites for all considerations except engineering at Site 5.

I. INTRODUCTION

The work described in this report was performed as a part of the Nevada Nuclear Waste Storage Investigations (NNWSI) project. The project is managed by the U.S. Department of Energy's (DOE) Nevada Operations Office, and is part of DOE's program to safely dispose of the radioactive waste from nuclear power plants. Sandia National Laboratories is one of the principal participating organizations.

DOE has determined that the safest and most feasible method currently known for the disposal of such wastes is to emplace them in mined geological repositories. The NNWSI project is conducting detailed studies of an area on and near the Nevada Research and Development Area which encompasses the southwestern corner of the Nevada Test Site (NTS). The purpose of the project is to determine the feasibility of developing a repository within the study area; the project has focused its exploration on Yucca Mountain.

Nuclear Regulatory Commission (NRC) 10 CFR 60 defines the technical and procedural requirements for licensing a geologic repository. Underground testing is required by the NRC to determine if a site will meet geological and design criteria for the underground repository facility. The Nuclear Waste Policy Act of 1982 requires site characterization, which includes excavation of an exploratory shaft (ES), to evaluate the suitability of a candidate site for a repository. The information required by NRC and DOE will be provided through scientific and engineering evaluations of the geologic formations beneath Yucca Mountain, if this site is selected as a candidate. The detailed characterization will include the siting and construction of an exploratory shaft as well as the construction of tunnels off the shaft and the associated implementation of in-situ experiments.

A screening program identified northern Yucca Mountain as a potential repository site (Sinnock and Fernandez, 1982). The Mountain is located along the western boundary of the NTS and intersects the common boundary of Nellis Air Force Bombing Range (NAFBR) and public lands controlled by the Bureau of Land Management (BLM) under the Department of Interior.

Yucca Mountain contains several formations of volcanic tuff that may be acceptable hosts for a repository. Two of these formations are above the water table, in the unsaturated zone. The Topopah Springs Member of the Paintbrush Tuff formation lies at a subsurface depth of approximately 100 to 1400 feet. Beneath Topopah Springs is the Calico Hills formation at a depth of approximately 1400 to 1800 ft. Also considered for the repository horizon are the Bullfrog and Tram Members of the Crater Flat Tuff formation. These lie within the saturated zone at subsurface depths of approximately 1800 to 2200 ft and 2700 to 3500 ft respectively (Spengler et al., 1981).

This report documents the process used to evaluate ES construction methods and the process used to screen potential ES sites. The resulting recommendations were made by the Ad Hoc TOC Committee. The Committee was first established as a Working Group on March 29, 1982; its purpose was to develop procedures for evaluating construction methods and screening sites. The procedures were approved and the Group became the AD Hoc TOC Committee at the request of the NNWSI Technical Integration Group* (TIG) on April 28, 1982. Committee members represented NNWSI technical organizations with functional responsibilities for geology, hydrology, repository design, ES design, ES test plan, and environment.

The Committee was charged with refining criteria for evaluating construction methods and potential sites and for implementing the TIG-approved methodology. It was to recommend the preferred method(s) and site(s) to the TIG by May 10 and June 1, 1982, respectively. The urgency with which the deliberations were to proceed was dictated by the then-existing ES construction schedule and by the associated environmental documentation requirements.

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*The TIG was composed of the senior project officers of all the organization participating in the NNWSI: SNL, LANL, LLNL, USGS, and Westinghouse.

The Committee used the most current information available at the time to evaluate the construction methods and the sites. Most of the data made available to the Committee (particularly by USGS but also by other project participants) was preliminary and unpublished. As a result, the information used by the Committee has been incorporated into this report without reference. Some of the information may have been refined in the interim, and when published may differ from that used by the Committee. However, no changes significant enough to alter the Committee's conclusions were anticipated by the TIG at the time the evaluation was made.

A final explanatory comment is warranted. In its evaluation of the Committee's recommendation, the Department of Energy placed considerably more weight on the factor of health and safety during shaft construction. Even with a substantially increased emphasis on this factor, the preferred construction method remained the same as recommended by the Committee.

II. DECISION METHODOLOGY

A. FIGURE OF MERIT TECHNIQUE

The Ad Hoc TOC Working Group chose the Figure of Merit (FOM) technique because it accommodated multiple alternatives for several influencing factors that incorporated professional judgments. The FOM technique allowed the Committee to structure each of the two complex decision problems so that all the important factors were considered together, after having been evaluated individually. The technique resulted in assigning a single number to each alternative. The number represented the worth of the alternative to the Committee. The technique had the added advantage of requiring independent consideration of the components of each factor. This allowed the Committee to develop insight into factors that required judgments based on a wide variety of technical expertise. The participation of several evaluators with a broad range of pertinent interests served to offset any individual biases which might occur.

In order to compare the alternatives associated with each decision, each alternative had to be specified to meet the same set of objectives and assumptions for the decision. Alternatives which did not satisfy these specifications were not considered. The Committee's first step in the FOM evaluation was to define the two sets of objectives to be met by the two actions being decided upon.

After establishing the objectives, two sets of criteria that allowed comparison of the alternatives were defined. The FOM was based on how well a given alternative performed for each criterion. The criteria included all the major areas of importance that affected the objectives as perceived by the Committee. These criteria were divided into subcriteria so that the significant components of each criterion could be considered. In general, major criteria and their associated subcriteria reflect concerns voiced and issues raised by NNWSI project investigators, by the former Working Group, or by consultants.

The next step was to determine the relative importance of the criteria, and within each criterion the importance of its subcriteria. Each criterion was assigned a weight that reflected its importance in satisfying the objectives and assumptions. The sum of the weights for the major criteria was defined to be unity. The subcriteria within each criterion were weighted in the same manner. A weighting factor for each subcriterion was computed by multiplying its weight by the weight of the associated criterion. The weighting factors were held constant for all alternatives.

The performance of the alternatives, or the ability of each alternative to satisfy each subcriterion, was evaluated and quantified by the Committee. This was done by using value judgments and reducing these to a numerical rating. The performance measures selected were 1, 3, or 5 where 5 meant "favorable," 3 meant "average," and 1 meant "less favorable." Each Committee member independently rated each alternative for its ability or inability to meet each subcriterion by assigning it a value of 1, 3, or 5.

Upon completing the individual Committee member rating, a Committee consensus of performance was assigned. The Committee used the numerical average of individual performance measures to grade the performance of a given alternative over a given subcriterion. However, ratings of "favorable" and "less favorable" (5 and 1) were never averaged together for a subcriterion. If individual performance judgments ranged from favorable to less favorable, the rationales used were carefully examined. Further discussion of the parameters or factors involved in defining the subcriterion, led by the Committee members or advisors with relevant expertise, resulted in establishing consistent ratings ranging from average to favorable or from average to less favorable. These ratings could then be averaged to obtain the performance measure. The numerical average was used rather than a negotiated consensus of a rating per criterion per alternative to reflect the varied expertise and background of Committee members.

The merit value of an alternative for a subcriterion was computed by multiplying the performance measure by the associated weighting factor. The FOM of an alternative was found by summing its subcriteria merit values.

B. EXPLORATORY SHAFT ASSUMPTIONS

Design objectives for the ES were established in the March 1982 Draft, "Conceptual Design Report" (Nelson, et al., 1982). Those design objectives were used to define the basic assumptions that guided the Committee in implementing the decision methodology.

The assumptions addressed safety, environment, technology and the purpose of the shaft. Additional assumptions were made concerning the construction start date and staging. The assumptions are given below.

1. Purpose of Shaft. The shaft will provide access to target horizons for excavation of underground openings, for moving of personnel, equipment, materials, and supplies between the surface and underground openings, and for housing the utility lines that service the openings.

2. Safety. The design and construction will incorporate established concepts and procedures that comply with current standards of the regulatory authorities.

3. Environment. The construction will avoid unacceptable long-term adverse impacts. Short-term adverse impacts will be mitigated.

4. Technology. The design concept and construction techniques will be based on established and proven technology. Care will be taken to assure that nothing will be done that would preclude use of the shaft as part of a future repository.

5. Construction Start Date. Shaft construction was anticipated to begin March 31, 1983.

6. Construction Staging. If the shaft were to be constructed in two stages, it would be constructed initially to a depth of about 1800* feet. The bottom of the shaft would be above the static water table. Breakouts would then access one or two unsaturated target horizons (Topopah Springs or Calico Hills) and exploratory activities including horizontal drilling would be completed to support a decision whether to explore the second unsaturated target horizon or to deepen the shaft to explore the saturated zone. If the decision were to explore the saturated zone, the shaft would be deepened to about 3500* feet. At that time, a breakout would access one or two saturated target horizons (Tram or Bullfrog) and exploratory activities including horizontal drilling in the saturated zone would be carried out.

*Both 1800 and 3500 feet are approximate depths. Actual depths to horizon(s) of interest are location dependent.

III. CONSTRUCTION METHOD EVALUATION

This chapter describes the evaluation of alternative construction methods that were considered for the exploratory shaft. Twelve alternatives were initially considered, but the Committee reduced the number to five for the FOM analysis.

A. OBJECTIVES

Two objectives were defined for the construction method evaluation. The primary objective of the ES would be to provide access to the rock unit targeted for repository development so that the target unit, the alternative rock units, and the strata above and below the target unit could be characterized in situ. The objective of the shaft construction would be to demonstrate that the rock of Yucca Mountain would support a large-diameter shaft.

Extensive site characterization will be necessary before a site is shown to be suitable for a repository. An important element of site characterization is the underground testing to be performed in situ in the host rock. As the NNWSI facility to be used for such testing, the ES would provide direct access to the target unit in the subsurface.

Large-diameter shafts have not been constructed in the Yucca Mountain area of the NTS. The extensive shaft construction experience for other locations on the NTS cannot be transferred unambiguously to the Yucca Mountain areas. One of the objectives of shaft construction is, therefore, to demonstrate that a large-diameter shaft can be successfully constructed at Yucca Mountain.

B. ALTERNATIVES

Two options for constructing the NNWSI ES were evaluted by the Committee. These were to use large hole drilling techniques to blind drill the shaft or to construct the shaft using conventional mining techniques. In addition, both vertical and declined shafts were considered. Because no decision had been made about whether to target a rock unit above or below the water table under Yucca Mountain, it was necessary to consider three cases for construction staging. These were:

1. Unsaturated zone only (0-1800 ft);
2. Saturated zone only (0-3500 ft);
3. Unsaturated zone (0-1800 ft); breakout and characterization; then saturated zone (1800-3500 ft).

The combination of the construction options, shaft types, and staging cases resulted in the Committee evaluating 12 alternatives for constructing the exploratory shaft. These alternatives are:

1. Drill the shaft to a depth of 1800 ft.
2. Mine a vertical shaft to a depth of 1800 ft.
3. Mine a decline to a depth of 1800 ft.
4. Mine a vertical shaft to a depth of 3500 ft.
5. Drill a vertical shaft to a depth of 3500 ft.
6. Mine a decline to 1800 ft; characterize the unsaturated; mine vertically to 3500 ft.
7. Mine a decline to 1800 ft; characterize the unsaturated; drill vertically to 3500 ft.
8. Drill vertically to 1800 ft; characterize the unsaturated; drill vertically to 3500 ft.
9. Mine a vertical shaft to 1800 ft; characterize the unsaturated; mine vertically to 3500 ft.
10. Drill vertically to 1800 ft; characterize the unsaturated; mine vertically to 3500 ft.
11. Mine a vertical shaft to 1800 ft; characterize the unsaturated; drill vertically to 3500 ft.
12. Mine a decline to 1800 ft; characterize the unsaturated; mine the decline to 3500 ft.

Alternatives 4 and 5 do not assume construction staging. They were used in the event the horizon selection process disqualified the unsaturated zone prior to initiation of construction.

Alternatives 6 and 7 would entail either conventional mining or drilling to 3500 ft following completion of the decline. The Committee considered it unrealistic to erect either a drill rig or a headframe at the end of the decline (1800 ft level). Therefore, it would be necessary to begin again at the surface either to intersect the decline or at another location. These alternatives would then become the same as the saturated zone cases of 0-3500 ft, except they would be in combination with the decline. The result would be a doubling of the cost and schedule and, therefore, was viewed by the Committee as unwarranted and inadvisable. Consequently, these options were not considered further.

Alternatives 8 and 11 were discounted by the Committee. Whether drilling or mining the vertical shaft in the unsaturated zone, mining a vertical shaft provided the logically preferred method for proceeding into the saturated zone. The following reasons were given for not evaluating 8 and 11:

- Independent of the means of constructing the shaft in the unsaturated zone, equipment would be in place to mine the drifts and alcoves. To proceed into the saturated zone after some exploration of the unsaturated zone either in parallel or sequentially (depending on unsaturated zone results) would involve less retrofit if the saturated zone were mined.

- The time required and the cost of dismantling the equipped shaft to position and operate the drill do not favor drilling.

. If drilling were to proceed into the saturated zone following dismantling of the equipped shaft, the availability of equipment and crews would require reevaluation. It was not known when (during the characterization of the unsaturated zone) an "onward" decision would be made, but schedule would then become critical and would require rapid contractor response times.

. The hydrology of the saturated zone (along with other site characterization needs) would require extensive evaluation if the unsaturated zone were inadequate. Mining would afford this opportunity and would not require plugging and sealing the drifts and alcoves created in the unsaturated zone.

. No shaft diameter stepdown would be required with mining.

. If mining with steel sets and lagging were used in the unsaturated zone, drilling would be impractical because of the potential for the drill head to damage the steel sets during tripping.

Alternatives 9 and 10 include the logical method of proceeding into the saturated zone following characterization of the unsaturated zone. The Figures of Merit were not computed for these two alternatives. They are merely staged-construction combinations of Alternatives 1 or 2 with 4. The Figure of Merit evaluations of Alternatives 1, 2, and 4 include 9 and 10.

The twelfth option, mining the decline to 3500 ft, was eliminated from further consideration. The resulting shaft was considered by the Committee to be impractical in length and not applicable for future use in the repository design.

C. CONSTRUCTION PROCESS

The following brief descriptions of the construction processes for the first five construction alternatives were used by the Committee in its evaluation.

Alternative One: Drill the Shaft to a Depth of 1800 Feet

Site Preparation. All surface facilities except those specifically needed for the mining operations would be installed. A 144-in. conductor pipe would be set to a depth of 100 ft and a concrete drill pad would be poured.

Drilling. After the conductor pipe has been set, a Class I drillrig would be brought in to drill a 142-in. diameter hole to a depth of 1800 ft. The Class I rig would then be removed and 122-in. inside diameter, steel casing would be installed using casing jacks to a depth of 1800 ft. The casing would then be cemented in place.

Breakout. A headframe and hoist system would be installed and the shaft internals secured. Breakout mining would then begin by cutting through the casing.

Alternative Two: Mine the Shaft to a Depth of 1800 Feet

Site Preparation. A headframe, hoist, and surface facilities would be constructed and the collar would be excavated before actual mining could begin. The collar and subcollar would be excavated to a depth of about 20 ft. After the collar and subcollar have been constructed, the shaft would be excavated to a depth of 100 ft with a diameter of approximately 14 ft. The slip forms would then be installed and the 100 ft of shaft liner poured to an inside diameter of 12 ft.

Mining. Mining would be done using the conventional drill, blast, and muck method. (That is, holes would be drilled for explosives, the explosives would be detonated, and the rubble removed to a depth of approximately 10 feet.) Slip forms would be lowered, and concrete would be poured behind the forms. The cycle would then be repeated. Shaft steel and permanent utilities could be installed as the shaft is sunk, or after the shaft has been completed. Geologic and hydrologic data collection would be done prior to liner installation.

Alternative Three: Mine a Decline to a Depth of 1800 Feet

Site Preparation. All surface facilities and a portal would be installed. Portal installation would consist of removing all unconsolidated material until hard rock was encountered. A concrete pad would then be poured, steel or timber sets for ground stabilization would be installed, and (if necessary) concrete would be poured around the sets for further stabilization.

Mining the Decline. Mining the decline would be accomplished by using conventional mining methods (that is, drill, blast, and muck) or by using a mechanical miner. For conventional drill and blast construction, a round would be drilled and blasted, rockbolts would be installed (if needed), a hauling device would remove the muck from the face, and the cycle would be repeated.

Alternative Four: Mine the Shaft to a Depth of 3500 Feet

Site Preparation. Site preparation for this option is identical to Alternative Two above.

Mining. The mining phase would be accomplished in the same way as described in Alternative Two, except that water control methods may be required to avoid flooding of the shaft in the saturated zone. Techniques to control water in-flow in the saturated zone vary according to in-flow rates, which would be determined from a nearby hydrology borehole. Rates in the range of 100 to 200 gpm could require pregrouting zones. At greater than 200 gpm, freezing or pregrouting is necessary.

Alternative Five: Drill a Vertical Shaft to a Depth of 3500 Feet

Site Preparation. All surface facilities except those specifically needed for mining operations would be installed. A 144-in. conductor pipe would be set to a depth of 100 ft and a concrete drill pad would be poured.

Drilling - The drilling phase would be accomplished the same way as described in Alternative One above. The 142- inch hole would be drilled to a depth of approximately 2050 ft, and a 122-inch casing would be installed. After the casing has been installed with casing jacks and cemented, the Class I rig would be installed over the shaft again, and a 120-inch hole would be drilled to a depth of 3500 ft. A 98-inch inside-diameter casing would then be installed from the surface to the total depth and would be cemented the entire length.

Breakout. A headframe and hoist system would be installed and the shaft internals secured. Breakout mining would then begin by cutting through the casing.

D. EVALUATION CRITERIA

Members of the Ad Hoc TOC Committee consulted with the NTS Support Office Test Construction Branch and with the mining and drilling A&E firm for the NTS. The Committee also met with a mining consulting and design firm. These discussions provided clarification of technical questions arising in the evaluation.

The objectives and criteria for shaft construction were identified by the Ad Hoc TOC Working Group under the lead of the ES Design and ES Test Design representatives. These objectives and criteria were further refined by the Committee after the consultations noted above.

The objectives of the shaft construction phase, together with the construction assumptions,* were used to derive the criteria and subcriteria for the construction method evaluation. The five criteria selected for evaluating the construction alternatives were 1) Site Characterization, 2) Constructibility, 3) Cost and Schedule, 4) Environment, and 5) Health and Safety. Each criterion as indicated in the following pages was further subdivided into component subcriteria.

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*Refer to DECISION METHODOLOGY in Section II for construction assumptions.

1. SITE CHARACTERIZATION

The objective addressed by this criterion is to provide access for in-situ characterization of the target unit, for alternative target units, and for overlying and underlying strata. Six subcriteria were identified as discriminators for the Figure of Merit evaluation.

a. Rock observation - The ability to examine rock characteristics along the shaft face including fracture spacing, orientations, apertures, and fillings.

b. Hydrologic observation - The ability to detect and measure flow rates of water. This includes the identification of perched water zones, significant in-flow from fracture zones, and possible aquifers within the saturated zone. Efforts would be made to measure quantities and qualities of water as well as the thickness of these intervals.

c. Access to multiple horizons - The relative ease of horizontal "breakout" from the shaft at various levels for characterization purposes.

d. Sample collection - The ability to obtain appropriate rock samples for petrologic and physical property analyses, and to obtain uncontaminated water samples for chemical and age analyses.

e. Rock damage - The ability of the construction method to minimize the alterations of the rock along the shaft face.

f. Loss of drilling fluid effects - The effect on the formation of lost construction fluids that could alter or mask natural conditions.

2. CONSTRUCTIBILITY

The objective addressed by this criterion is to demonstrate that the shaft can be constructed. The objective also addresses the Technological Assumption. Five subcriteria were identified as discriminators for the Figure of Merit evaluation.

a. Water and ground control - The ability of the method to deal with adverse geologic and hydrologic problems such as sloughing of the hole in highly fractured or friable intervals, swelling zones in altered horizons, and excessive in-flow of groundwater into the shaft.

b. Unanticipated conditions - The ability of the method to deal with unexpected adverse conditions or unanticipated modifications of the exploration plan.

c. Shaft size - The ability of the method to maintain verticality and provide flexibility in diameter selection to meet exploration requirements.

d. Experience availability - Refers to the number of potential contractors and their experience with the construction method.

e. Overbreak - The ability of the method to minimize enlargement beyond the intended diameter.

3. COST AND SCHEDULE

This criterion addresses both evaluation objectives, i.e., to provide access for in-situ characterization and to demonstrate that the shaft can be constructed. Four subcriteria were identified as discriminators for the Figure of Merit evaluation.

a. Construction time - The relative time required for the method to perform the construction (including the lead time to obtain supporting equipment).

b. Cost - The relative cost (capital and operating expense) of the construction and the supporting equipment.

c. Equipment availability - The relative availability of the equipment necessary to accomplish the construction.

d. Contractor/Craft availability - The relative availability of contractors to perform the construction.

4. ENVIRONMENT

This criterion addresses the Environment Assumption. It recognizes that different construction methods involve different levels of environmental impact and thus require different levels of mitigation. Four subcriteria were identified as discriminators for the Figure of Merit evaluation.

a. Reclamation - The relative difficulty of recontouring and restoring the disturbed surface area.

b. Surface disturbance - The relative surface area disturbed by the construction method.

c. Effluent control - Difficulty of control and relative hazard of effluents (water, mud, other drilling fluids, spoils, sewage, etc.).

d. Air quality - Ability to control to acceptable levels fugitive dust from surface construction and roads, explosive shot gases, and emissions from internal combustion engines.

5. HEALTH AND SAFETY

This criterion addresses the Safety Assumption. Its purpose is to protect worker health and safety. Two subcriteria were identifed as discriminators for the Figure of Merit evaluation.

a. Industrial hazards - The relative risk of the construction method. The industrial hazards of the construction methods are minimized by following the requirements of NTS procedures and regulatory standards under MSHA and OSHA, but vary among the alternatives.

b. Working conditions - The relative comfort and convenience of workers exposed to varying conditions of temperature, humidity, and dust.

E. WEIGHT OF CRITERIA AND SUBCRITERIA

To compute the Figure of Merit, each criterion and subcriterion was assigned a weight that reflects its importance in satisfying the objectives. The sum of the weights for the criteria as well as for each set of subcriteria, is unity. The consensus assignment of weights by the Committee is given in Table 3. The weighting factors, the products of the weight of each subcriterion and associated criterion, are given in Table 4. The order in the table is from most important to least important. The Committee carefully considered the relative rank of each subcriterion prior to adopting these weighting factors for use in the FOM computation.

Table 3. Weights of Criteria and Subcriteria for Construction Method Evaluation

CRITERIA	WEIGHT	SUBCRITERIA	WEIGHT
		Rock Observation	0.245
		Hydrologic Observation	0.245
1. Site Characterization	0.45	Access to Multiple Horizons	0.220
		Sample Collection	0.170
		Rock Damage	0.060
		Loss of Drilling Fluid Effects	0.060
		Subtotal	1.000
		Water and Ground Control	0.34
		Unanticipated Conditions	0.26
2. Constructibility	0.30	Shaft Size	0.17
		Experience Availability	0.14
		Overbreak	0.09
		Subtotal	1.00
		Construction Time	0.35
3. Cost and Schedule	0.15	Cost	0.35
		Equipment Availability	0.15
		Contractor/Craft Availability	0.15
		Subtotal	1.00
		Reclamation	0.45
4. Environment	0.05	Surface Disturbance	0.25
		Effluent Control	0.20
		Air Quality	0.10
		Subtotal	1.00
5. Health and Safety	0.05	Industrial Hazards	0.60
		Working Conditions	0.40
		Subtotal	1.00
TOTAL	1.00		

Table 4. Relative Weighting Factors for Construction Method Evaluation

SUBCRITERIA	WEIGHTING FACTOR	CUMULATIVE WEIGHTING
Rock Observation	0.110	0.110
Hydrologic Observation	0.110	0.220
Water and Ground Control	0.102	0.322
Access to Multiple Morizons	0.099	0.421
Unanticipated Conditions	0.078	0.499
Sample Collection	0.077	0.576
Construction Time	0.053	0.629
Cost	0.053	0.682
Shaft Size	0.051	0.733
ExPerience Availability	0.042	0.775
Industrial Hazards	0.030	0.805
Rock Damage	0.027	0.832
Loss of Drilling Fluid Effects	0.027	0.859
Overbreak	0.027	0.886
Equipment Availability	0.023	0.909
Contractor/Craft Avallablllty	0.023	0.932
Reclamation	0.023	0.955
Working Conditions	0.020	0.975
Surface Disturbance	0.013	0.988
Effluent Control	0.010	0.998
Air Quality	0.005	1.003*

*Error of .003 due to roundinq.

F. PERFORMANCE COMPARISON

Supplementary information for the performance comparison of the three construction methods is given below.

1. SUPPLEMENTARY INFORMATION

a. Site Characterization - The purpose of site characterization is to sufficiently understand the site and thus be able to design a waste package and repository that are site specific and to analyze or bound the radionuclide isolation capability of that combination of waste package, repository, and site. The design and isolation analyses are needed before a decision can be made to construct a repository at the site. The principal focus of site characterization would be to understand the hydrologic characteristics of the pristine rock.

The criteria defined for site characterization were based on the data needs for isolation analyses. The relative ability to provide the required data is the measure of the construction method performance. The weighting factors assigned to the first four site characterization subcriteria reflected the importance to isolation analyses of rock observation, hydrologic observation, multiple horizon access, and sample collection. All of the data needed for these subcriteria would be readily available from a mined shaft. The declined shaft would provide ideal rock observation conditions, but hydrologic observation might be hampered in some zones if grouting were necessary. The shaft wall would be easily accessible to the geologist and hydrologist for examination during mining. Tests could be performed on the newly exposed rock, rock samples from specific depths collected, and hydrological data collection initiated before the shaft liner for each section was installed.

The data needed for these four subcriteria would not be available during drilling of a shaft. Samples could not be collected except as brought to the surface in the drilling mud. Other data would have to be obtained from drilling horizontal boreholes at intervals along the shaft after the liner is installed and the shaft is equipped. Breakout zones would be identified using cores from these boreholes in conjunction with remote sensing data and vertical borehole data. No direct observation would be possible. Mining of breakout rooms off the shaft would require cutting through the liner. Several horizons would be accessible, but the identification process would give little assurance of optimization.

There would be some rock damage from blasting during mining, more so in a decline than in a vertical shaft, but very little in drilling. The potential for damage from drilling fluids injected into the unsaturated zone formations was believed to be high. None of the geohydrologic exploration holes drilled to date had maintained drilling fluid circulation while drilling throughout the unsaturated zone. Hole USW G-1 lost to (i.e., injected into) the rock formation an average of 380 gallons of drilling fluid per foot during drilling in the unsaturated zone. The hole diameter was nominally 3.9 inches.

The fluid loss records for USW G-1 could not be used to extrapolate the drilling fluid loss from drilling a 12-foot-diameter hole maintaining a 200-foot column of mud while drilling past a given formation. The diameter of the contaminated zone depends on the short-term effective porosity, but clearly, there would be a significant potential for contaminating hundreds of feet around the exploratory shaft with the polymer-clay drilling fluid. Minimizing the drilling-fluid pressure head would minimize the extent of contamination, but USW G-1 drilling fluid losses indicate that it would be a serious problem.

Drilling fluid loss in the saturated zone should be minimal, assuming that the drilling-fluid would be maintained at approximately the standing water level in the hole. The impacts of contamination in the saturated zone would be much smaller than in the unsaturated zone.

The water use in mininq the exploratory shaft was estimated at 330 gallons per axial foot, used in percussion drilling of 10-foot-deep blast-round holes for explosives. The assumption was made that most of the water would be removed with the broken rock after the blasting round. Since the pressure head would be much smaller than for borehole drilling, only a fraction of this water would be expected to contaminate the formations in the unsaturated zone. Both construction methods would introduce and lose fluid to the formation. However, with mining only a seepage loss of clear water is expected while drilling would inject major volumes of polymer mud under pressure.

b. Constructibility - The ability to control water inflow and shaft wall sluffing are extremely important in constructing the shaft. Therefore, the weighting factor for this subcriterion was second only to the two primary site characterization subcriteria. The shaft liner for a mined shaft would be installed in sections as sinking progressed. The ground control afforded in a mined, vertical shaft would be very high as only a short section of rock would be exposed at a given time. For a decline, control of the overlying exposed rock could prove difficult in a fractured zone.

A mined vertical shaft can be made watertight so that both horizontal and vertical water movements through and along the shaft lining can be eliminated. High transmissivity zones in the saturated zone could present mining problems, in some cases potentially requiring pressure grouting or other specialized techniques depending on water in-flow rates. In-flow rates were expected to be low enough, even in the saturated zone, that flooding of the shaft during construction was not anticipated.

Installing a watertight shaft lining and preventing vertical water movement can be achieved for a drilled shaft without any basic difficulties. A major concern with installing watertight linings in drilled shafts was the vertical alignment of the rotary drilled shafts. In order to solve problems connected with out-of-plumbness of the lining tube, a larger diameter of the drill shaft usually has to be selected.

The impact of unanticipated adverse conditions on shaft construction was considered to be very important by the Committee. We considered caving and flooding. The risk of caving exists during mining, but only for a 20-ft section at a time because the liner would be installed as the shaft advances. Caving would have less impact on a mined shaft because the existence of bad ground would be recognized and corrected before a major problem could develop. However, if a drilled shaft caved in during drilling, the shaft would probably be lost, along with the downhole drilling apparatus. At the least, a major "fishing" operation would be required, then cementing and redrilling through the caved zone would have to be done. The risk of caving in a drilled shaft exists until the shaft liner is installed after the shaft has been drilled to the total depth.

Flooding during construction in a mined shaft would have greater impact than in a drilled shaft, but the low rate of water in-flow expected indicates that flooding should not occur. If it did, the shaft section could be pressure grouted and mining would continue. Unanticipated changes in exploration plans, such as depth of breakout zones, stopping to characterize a zone or changing the shaft diameter, could be very difficult to accommodate during drilling of a shaft.

Although there has been extensive experience with shaft drilling at the NTS, it has generally been for smaller diameter shafts. The diameter of the shaft would be limited by the equipment available. Experienced mining firms were readily available.

The potential for overbreak does not exist with drilling, unless caving occurs. Overbreak during mining would be expected and would result in widening of the shaft wherever it occurred.

c. Cost and Schedule - The objective of constructing the ES would be to obtain access to the subsurface and to obtain reliable site characterization data. Although rate and cost of construction are important, the fastest or least expensive method may not provide the necessary data. For this reason, the subcriteria under cost and schedule were given lower weighting factors than were site characterization and constructibility.

No comparative studies of mining versus drilling costs and time requirements were available to the Committee. However, discussions with consultants led to the assumption that drilling could proceed faster than mining, and would cost about the same for the unsaturated zone. Mining in the saturated zone was assumed to be more costly. The time required for and the cost of geologic mapping of the shaft walls prior to lining the mined shaft would increase the cost of mining the shaft over the cost of drilling it.

It was expected that contractors would be available who had the necessary equipment to mine the shaft, although lead time could be a problem. No outside contractors were identified who had the drilling equipment although existing NTS contractors had drill rigs which could be modified to drill the shaft with a minimally acceptable diameter. Scheduling the NTS contractor rigs could present a problem.

For a declined shaft, access for moving men, materials, and equipment is limited by the inclination of the opening. The upper limit of inclination should be 14 degrees (25%). Inclination at 10 degrees (17.6%) is optimum. However, such inclination would result in an extremely long decline affecting costs of capital investment and operational maintenance. An exploratory decline access to a 2000-ft depth at the maximum inclination (14 degrees) would be 8300 feet long. For 3500 feet of depth, the length of the decline would be 14,500 feet. Both these lengths are unconventionally large. Ventilation in such airways would be difficult. Maintenance and equipping of such long declines would be costly.

d. Environment - The relative impacts of shaft construction are dependent on the site selected; for example, construction of a mud pit on the mountaintop would cause greater surface disturbance and increase the difficulty of controlling effluents relative to mining a shaft at the same location. However, because no site had been selected, the influence of topography could not be considered.

The surface disturbance associated with drilling the shaft was assumed to be less than for mining the shaft. The area required for a mud pit would be less than that for a muck pile. The volume of topsoil required to cover over and reclaim the mud pit would also be less, so that a smaller borrow area would be disturbed for the reclamation. The construction pads were assumed to be the same size.

The ability to control effluents would be dominated by drilling fluid containment measures. If the large volume of drilling fluids required were recovered from the shaft, it would be necessary to ensure that the impermeable clay and the rock fines in the fluids were not dispersed at the surface. Maintaining the integrity of mud-pit berms had proven to be problematic in the alluvial soils of the mountain. Controlling excess water associated with mining muck was considered to be simpler, because it could be contained for the short time required for percolation into the underlying alluvial soils. (The mud-pit liner would prevent drilling fluid percolation.) No information was available to indicate whether leaching from the muck pile might become a problem. It was assumed that the leachate chemistry of the muck (broken tuff) would be the same as that of the alluvium (decomposed tuff).

Air quality would be impacted equally by surface construction for drilling or mining. However, mining would result in shot gases and dust being exhausted from the shaft with each blasting round. Muck handling and muck pile construction would also create dust. Diesel emissions would be greater for drilling as the drilling rig was assumed to be diesel powered.

e. Health and Safety - Both drilling and mining a large shaft are hazardous to operations personnel. Accidents in either type of construction have a high potential for serious bodily injury or fatality.

The safety record for large-hole drilling operations at the NTS is extremely good. The NTS contractor attitudes toward safety, the administrative controls and procedures that are implemented, and the safety associated with working conditions are excellent. As a result, less than half as many accidents per million man-hours worked have been reported for the NTS drilling operations as were reported for commercial shaft mining. Because of the combination of the inherently less hazardous operation and the NTS safety practices, shaft drilling has the better safety record.

Mining a declined shaft would be less hazardous than mining a vertical shaft. This is because falls from a great height cannot occur in a decline. Similarly, objects cannot be dropped great distances. However, because mining requires that miners work down in the shaft to construct and line it, mining would be more hazardous than drilling.

The working conditions during shaft mining are worse than conditions during drilling. The drill crew remains at the surface, while the mining crew must work in a dusty, humid atmosphere. Although the shaft air would be exhausted and replaced after each blasting round and ventilation systems would be installed as the shaft bottom advanced, conditions would still be less comfortable than those for a drilling crew at the surface.

2. RELATIVE PERFORMANCE

The relative performance of the alternatives was evaluated by the Committee. The performance measure of 1, 3, or 5 was assigned by each Committee member to each alternative based on its perceived ability to meet each criterion. This rating was done for two cases: saturated and unsaturated. In the unsaturated zone case, drilling, mining vertically, and mining a decline were rated relative to each other. In the saturated case (progressing from the surface to a total depth of 3500 ft without stopping for unsaturated zone characterization), two alternatives of drilling and conventional sinking were rated relative to each other. The average performance measures are shown in Table 5 to allow comparison of performance between alternatives.

G. FIGURE OF MERIT

The merit value of each alternative for each subcriterion is the product of the weighting factor and the performance measure. Therefore, the maximum possible merit value for this application was 0.55, for the most important subcriterion, and the minimum possible was 0.005 for the least important subcriterion. The FOM is the sum of the merit values. An FOM of 5.0 for an alternative would indicate "highest favorability" and an FOM of 1.0 would indicate "lowest favorability." The merit values and their sums are shown in Table 6. The Figures of Merit are summarized in Table 7. The complete computation form is shown in Table 8.

H. CONCLUSION

The unanimous conclusion of the Ad Hoc TOC Committee was that the highest ranked alternative for constructing the NNWSI Exploratory Shaft would be to mine it vertically to the horizon(s) of interest. If new hydrologic data useful for estimating water in-flow rates for sections of the saturated zone become available after initiation of the unsaturated zone shaft construction and prior to a decision to proceed with mining in the saturated zone, the recommendation to mine in the saturated zone should be reevaluated in light of the new data.

Table 5. Performance Comparison of Construction Alternatives

SUBCRITERIA	PERFORMANCE MEASURES Unsaturated C1	C2	C3	Saturated C4	C5
Rock Observation	1.3	4.6	5.0	4.6	1.3
Hydrologic Observation	1.3	5.0	4.6	5.0	1.6
Access to Multiple Horizons	2.3	5.0	5.0	5.0	2.3
Sample Collection	1.0	5.0	5.0	5.0	1.0
Rock Damage	4.6	3.3	2.6	3.3	4.6
Loss of Drilling Fluid Effects	1.0	5.0	5.0	5.0	1.0
Water and Ground Control	2.0	4.6	2.0	4.3	2.3
Unanticipated Conditions	2.3	4.3	4.0	4.0	2.3
Shaft Size	1.0	4.0	5.0	4.6	1.3
Experience Availability	3.0	4.0	4.0	3.6	3.0
Overbreak	5.0	2.6	2.3	2.6	5.0
Construction Time	4.6	3.3	1.0	2.6	4.6
Cost	4.3	4.0	1.0	3.0	4.6
Equipment Availability	2.6	4.0	4.0	4.0	2.6
Contractor/Craft Availability	2.6	3.6	3.6	3.6	2.6
Reclamation	3.6	3.0	1.6	3.3	3.3
Surface Disturbance	4.0	3.0	2.3	2.6	4.0
Effluent Control	2.0	3.0	3.0	3.0	2.0
Air Quality	3.3	2.3	2.0	2.3	3.3
Industrial Hazards	5.0	2.0	3.0	1.3	4.3
Working Conditions	5.0	2.0	3.0	1.6	4.3

Alternatives: C1--Drilled Vertically to 1800 ft
C2--Mined Vertically to 1800 ft
C3--Mined Decline to 1800 ft
C4--Mined Vertically to 3500 ft
C5--Drilled Vertically to 3500 ft

Table 6. Merit Values of Construction Alternatives for Each Subcriterion

		MERIT VALUES				
		Unsaturated			Saturated	
SUBCRITERIA	Maximum	C_1	C_2	C_3	C_4	C_5
Rock Observation	0.55	0.14	0.51	0.55	0.51	0.14
Hydrologic Observation	0.55	0.14	0.55	0.51	0.55	0.18
Multiple Horizons Access	0.50	0.23	0.50	0.50	0.50	0.23
Sample Collection	0.39	0.08	0.39	0.39	0.39	0.08
Rock Damage	0.14	0.12	0.09	0.07	0.09	0.12
Lost Drilling Fluid Effect	0.14	0.03	0.14	0.14	0.14	0.03
Subtotal	2.27	0.74	2.18	2.16	2.18	0.78
Water and Ground Control	0.51	0.20	0.47	0.20	0.44	0.24
Unanticipated Conditions	0.39	0.18	0.34	0.31	0.31	0.18
Shaft Size	0.26	0.05	0.20	0.26	0.24	0.07
Experience Available	0.21	0.13	0.17	0.17	0.15	0.13
Overbreak	0.14	0.14	0.07	0.06	0.07	0.14
Subtotal	1.51	0.70	1.25	1.00	1.21	0.76
Construction Time	0.27	0.24	0.18	0.05	0.14	0.24
Cost	0.27	0.23	0.21	0.05	0.16	0.24
Equipment Available	0.12	0.06	0.09	0.09	0.09	0.06
Contractor/Craft Available	0.12	0.06	0.08	0.08	0.08	0.06
Subtotal	0.78	0.59	0.56	0.27	0.47	0.60
Reclamation	0.12	0.08	0.07	0.04	0.08	0.08
Surface Disturbance	0.07	0.05	0.04	0.03	0.03	0.05
Effluent Control	0.05	0.02	0.03	0.03	0.03	0.02
Air Quality	0.03	0.02	0.01	0.01	0.01	0.02
Subtotal	0.27	0.17	0.15	0.11	0.15	0.17
Industrial Hazards	0.15	0.15	0.06	0.09	0.04	0.13
Working Conditions	0.10	0.10	0.04	0.06	0.03	0.09
Subtotal	0.25	0.25	0.10	0.15	0.07	0.22
FIGURES OF MERIT	5.08*	2.45	4.24	3.69	4.08	2.51

Alternatives:
- C1--Drilled Vertically to 1800 ft
- C2--Mine Vertically to 1800 ft
- C3--Mined Decline to 1800 ft
- C4--Mined Vertically to 3500 ft
- C5--Drilled Vertically to 3500 ft

*Error of 0.08 due to round-off

Table 7. Figures of Merit for Construction Alternatives

CONSTRUCTION ALTERNATIVE	FOM	RANK
Unsaturated Zone (0-1800 ft)		
1. Mined Vertical Shaft	4.24	1
2. Mined Declined Shaft	3.69	2
3. Drilled Vertical Shaft	2.45	3
Saturated Zone (0-3500 ft)		
4. Mined Vertical Shaft	4.08	1
5. Drilled Vertical Shaft	2.51	2

Table 8. Figure of Merit Evaluation for Exploratory Shaft Construction Alternatives

CRITERIA	WEIGHT	SUBCRITERIA	WEIGHT	WEIGHTING FACTOR	PERFORMANCE MEASURE C_1	C_2	C_3	C_4	C_5	MERIT VALUES C_1	C_2	C_3	C_4	C_5
Site Characterization	0.45	Rock Observation	0.245	0.110	1.3	4.6	5.0	4.6	1.3	0.14	0.51	0.55	0.51	0.14
		Hydrologic Observation	0.245	0.110	1.3	5.0	4.6	5.0	1.6	0.14	0.55	0.51	0.55	0.18
		Access to Multiple Horizons	0.22	0.099	2.3	5.0	5.0	5.0	2.3	0.23	0.50	0.50	0.50	0.23
		Sample Collection	0.17	0.077	1.0	5.0	5.0	5.0	1.0	0.08	0.39	0.39	0.39	0.08
		Rock Damage	0.06	0.027	4.6	3.3	2.6	3.3	4.6	0.12	0.09	0.07	0.09	0.12
		Loss of Drilling Fluid Effects	0.06	0.027	1.0	5.0	5.0	5.0	1.0	0.03	0.14	0.14	0.14	0.03
							Subtotal			0.74	2.18	2.16	2.18	0.78
Constructibility	0.30	Water and Ground Control	0.34	0.102	2.0	4.6	2.0	4.3	2.3	0.20	0.47	0.20	0.44	0.24
		Unanticipated Conditions	0.26	0.078	2.3	4.3	4.0	4.0	2.3	0.18	0.34	0.31	0.31	0.18
		Shaft Size	0.17	0.051	1.0	4.0	5.0	4.6	1.3	0.05	0.20	0.26	0.24	0.07
		Experience Availability	0.14	0.042	3.0	4.0	4.0	3.6	3.0	0.13	0.17	0.17	0.15	0.13
		Overbreak	0.09	0.027	5.0	2.6	2.3	2.6	5.0	0.14	0.07	0.06	0.07	0.14
							Subtotal			0.70	1.25	1.00	1.21	0.76
Cost and Schedule	0.15	Construction Time	0.35	0.053	4.6	3.3	1.0	2.6	4.6	0.24	0.18	0.05	0.14	0.24
		Cost	0.35	0.053	4.3	4.0	1.0	3.0	4.6	0.23	0.21	0.05	0.16	0.24
		Equipment Availability	0.15	0.023	2.6	4.0	4.0	4.0	2.6	0.06	0.09	0.09	0.09	0.06
		Contractor/Craft Availability	0.15	0.023	2.6	3.6	3.6	3.6	2.6	0.06	0.08	0.08	0.08	0.06
							Subtotal			0.59	0.56	0.27	0.47	0.60
Environment	0.05	Reclamation	0.45	0.023	3.6	3.0	1.6	3.3	3.3	0.08	0.07	0.04	0.08	0.08
		Surface Disturbance	0.25	0.013	4.0	3.0	2.3	2.6	4.0	0.05	0.04	0.03	0.03	0.05
		Effluent Control	0.20	0.010	2.0	3.0	3.0	3.0	2.0	0.02	0.03	0.03	0.03	0.02
		Air Quality	0.10	0.005	3.3	2.3	2.0	2.3	3.3	0.02	0.01	0.01	0.01	0.02
							Subtotal			0.17	0.15	0.11	0.15	0.17
Health and Safety	0.05	Industrial Hazards	0.60	0.030	5.0	2.0	3.0	1.3	4.3	0.15	0.06	0.09	0.04	0.13
		Working Conditions	0.40	0.020	5.0	2.0	3.0	1.6	4.3	0.10	0.04	0.06	0.03	0.09
							Subtotal			0.25	0.10	0.15	0.07	0.22
					FIGURES OF MERIT					2.45	4.24	3.69	4.08	2.51

Alternatives: C1--Drilled Vertically to 1800 Ft
C2--Mined Vertically to 1800 Ft
C3--Mined Decline to 1800 Ft
C4--Mined Vertically to 3500 Ft
C5--Drilled Vertically to 3500 Ft

The Committee presented the evaluation to the NNWSI Technical Integration Group on May 12, 1982. After reviewing the factors considered and examining the Figure of Merit computation, the TIG unanimously agreed with the recommendation. The TIG noted that mining a vertical shaft would be consistent with recommendations made by peer reviewers during the August 1981 NNWSI Peer Review (NVO-196-27).

IV. SITE SCREENING

This chapter describes the evaluation of alternative construction sites that were considered for the ES. Five alternatives were identified and compared by the FOM technique. The evaluation was made considering both conventional mining and drilling of vertical shafts. This was necessary because no decision had been made regarding the construction method.

A. OBJECTIVES

Four objectives were defined by the Ad Hoc Working Group for site screening. The TIG instructed the Committee to place emphasis on the unsaturated zone of rock above the water table. However, the saturated zone was also to be considered. The four objectives approved by the TIG as input to the Committee's work were:

1. Select an Exploratory Shaft site from which to explore target units within the exploration block with emphasis on the unsaturated zone.

2. Exploration from the shaft must be capable of accessing unsaturated and saturated target units to both confirm expected favorable conditions and to assess potentially adverse conditions.

3. Known areas of potentially adverse subsurface conditions must be avoided for shaft siting, but these areas must be accessible for testing from the shaft.

4. Surface areas where shaft construction would result in unmitigable environmental impact must be avoided.

B. SCREENING CRITERIA

The criteria for site selection were identified by the Ad Hoc Working Group, and were subsequently refined by the Committee. The procedure defined by the Working Group for identifying suitable sites was to first establish site screening criteria, then to gather the data required. They would then apply the scientific criteria to define acceptable areas, and apply exclusionary criteria to define unacceptable areas. The Committee essentially followed this procedure to identify preferred areas. The screening criteria were in four categories: 1) Scientific, 2) Engineering, 3) Environmental, and 4) Nontechnical.

1. SCIENTIFIC

Boundary Set-Back. The ES site was to be located within the interior of the exploration block so that the subsurface facilities would be within favorable rock conditions judged typical of the exploration block as a whole.

Preferred sites would be identified as follows:

. ES sites more than 500 feet from the western boundary structure at the surface were to be ranked higher than those less than 500 feet.

. ES sites more than 1000 feet from the northern boundary structure at the surface (Drill Hole Wash) were to be ranked higher than those less than 1000 feet.

. ES sites more than 2000 feet from the eastern boundary structure at the surface were to be ranked higher than those less than 2000 feet.

. ES sites north of an east-west line 4000 feet north of USW-H3 were to be ranked higher than those south of the line.

The boundaries used by the committee for the Yucca Mountain exploration block were provided by the USGS and are shown in Figure 1 along with the boundary projection at depth at the base of the Tram unit.

Discussions were held with appropriate USGS personnel to obtain an interpretation of the character of the exploration block bounding structures. USGS personnel had mapped the Yucca Mountain area in detail and were knowledgeable concerning the structure. As a result of the discussions, a set-back distance was established so that the Exploratory Shaft would be located far enough from bounding structures that there would be a low

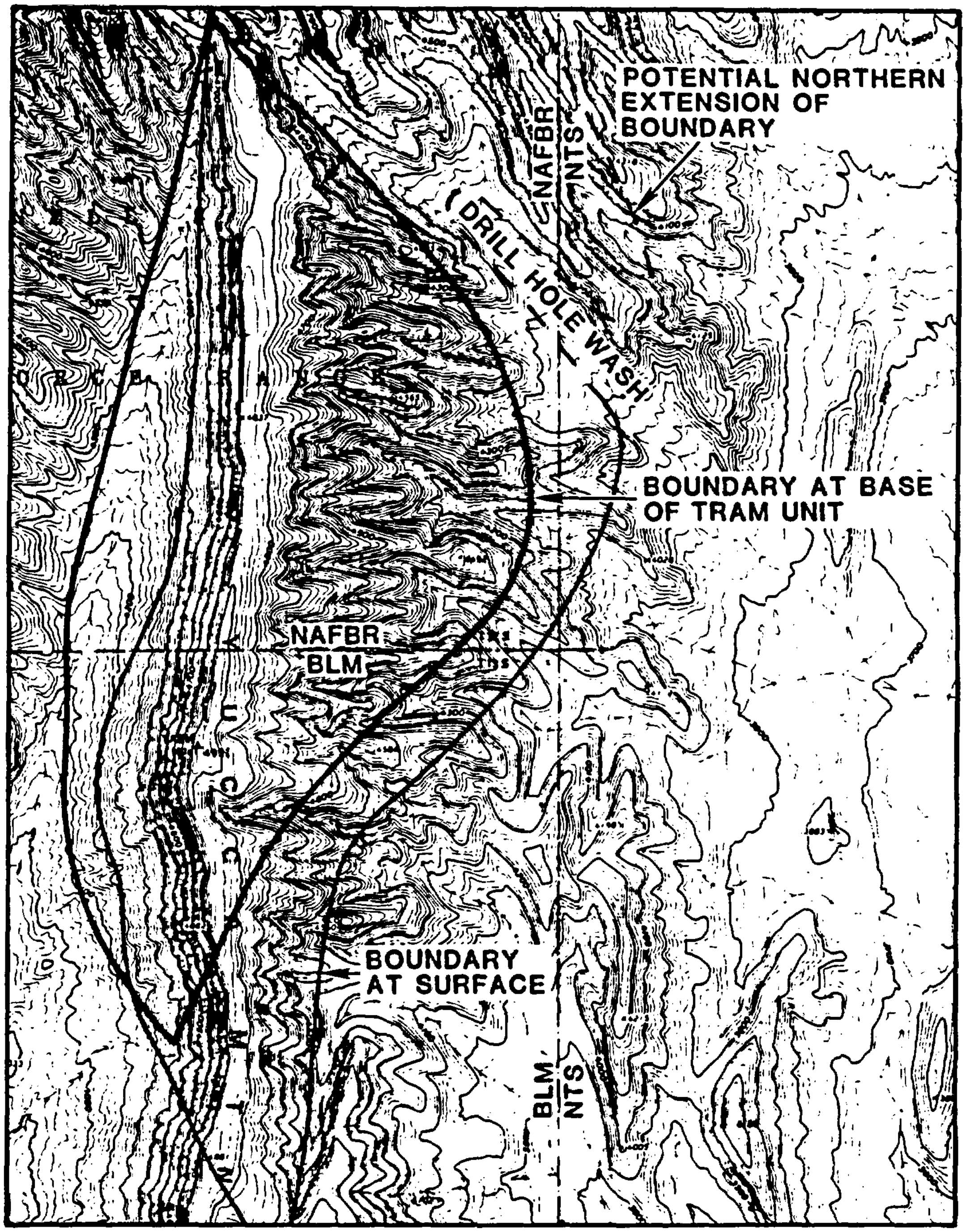

Figure 1. Exploration Block

likelihood that the shaft itself and drifts from the shaft would encounter fractures associated with those structures.

The western boundary structure appeared to be relatively sharp on its eastern edge. A set-back distance of 500 feet to the east was considered sufficient to place the shaft well out of that zone of faulting.

There was concern about the possibility of structures within Drill Hole Wash. It was generally agreed that there were bedrock fractures in Drill Hole Wash to the east of drill hole USWH-1; however, the current interpretation was that bedrock fractures did not extend to the west in Drill Hole Wash beyond USWH-1. This had not been clearly established. To be conservative and allow for the possibility of bedrock fractures west of USWH-1, a set-back distance of 1000 feet to the south of Drill Hole Wash was established. This would place the shaft well out of a possible zone of faulting within Drill Hole Wash, but close enough to allow penetration of the Drill Hole Wash fractures by horizontal drilling if necessary.

The faulting that bounds the exploration block on the east is a zone of west-dipping faults. The boundary is not well defined. Because of the west dip and the lack of definition of the boundary, a set-back distance of 2000 feet was used to place the shaft outside of that zone of faulting.

The Abandoned Wash area east and northeast of drill hole USW H-3 is an area of numerous, closely spaced faults with small offsets. This faulting appeared to die out to the north toward the central portion of the exploration block. Siting the Exploratory Shaft 4000 feet or more north of USW H-3 was considered to be sufficient to avoid the faulting observed in the Abandoned Wash area.

> **Vertical Thickness of Target Units. The ES site was to be located to confirm expected favorable subsurface conditions, with priority given to thick target units having homogeneous physical properties.**

Preferred ES sites would be identified as follows:

- Higher ranked ES sites would be those that provided a maximum vertical thickness of target units in the unsaturated zone.

- Higher ranked ES sites would be those that provided the greatest vertical thickness of target units in the saturated zone, consistent with maximizing thickness in the unsaturated zone.

The Exploratory Shaft should intersect the greatest possible thicknesses of units of interest in order to ensure the capability to mine subsurface facilities in any of those units. However, the unsaturated zone units thicken to the north and the

Distance to Potentially Adverse Structure. The ES site was to be located to explore one or more potentially adverse structures within the block if at the time of ES site selection such structures were interpreted to exist. Preference would be given to those structures that were expected to influence repository performance.

Preferred ES sites with respect to potentially adverse structures were to be identified as follows:

- ES sites that would have subsurface facilities (excluding horizontal boreholes) located 1000-2000 feet from potentially adverse structures would be ranked higher than those that would have subsurface facilities located less than 1000 feet or more than 2000 feet from potentially adverse structures. (Note: Allowances for dipping structures was made.)

- ES sites that would have subsurface facilities (excluding horizontal boreholes) closer than 100 feet to a potentially adverse structure would be excluded.

The Exploratory Shaft should be located far enough from potentially adverse structures within the block so that there would be a low likelihood that the shaft itself and drifts from the shaft would encounter fractures associated with those structures. Yet, the shaft should be sited close enough to the potentially adverse structure that it could be penetrated and evaluated by horizontal drilling from the shaft. A 1000-foot set-back distance was judged to be sufficient to place the shaft outside the zones of fracturing associated with the structures.

Because two thousand feet was considered as a reasonable maximum distance for horizontal drilling from the Exploratory Shaft, a set-back distance of 1000-2000 feet was used in this criterion.

> **Volume Explored. The ES was to be located to allow exploration of the largest possible volume of the target unit or units.**

Preferred sites would be at least one drilling radius away from the block boundary.

The Exploratory Shaft should be located to allow horizontal or angle drilling radially from the ES over as much of 360 degrees as possible in each unit of interest.

2. <u>ENGINEERING</u>

> **Constructibility. The ES was to be located to ensure its constructibility.**

The ES would be located away from adverse structural features which would pose major engineering or construction hazards. Highly transmissive zones, major fault rubble zones, and areas of squeezing clay should be avoided.

> **Terrain Effects. The ES was to be located to assure the ability to construct the facilities in an economic manner with low risk for construction problems.**

The ES was to be located where terrain did not pose major engineering or construction problems. Adverse topography with steep slopes would pose unnecessary problems, which would require additional construction risk and cost to overcome. Sites in areas of adverse topography were excluded. The ES was to be located where the effect of flash flooding could be avoided or economically accommodated. Flash flooding is not too likely to happen, but its consequences could be major during the construction and the operation of the ES. Depending on the method of construction, the ES would be located where the waste rock or mud from the construction could best be accommodated. The construction of a muck pile or a mud pit must be considered in locating the ES. The effect of the terrain on the location differs with the construction method.

Repository Compatibility. The ES was to be located where it would be of most use and have the least adverse impact on the potential later development of a repository.

The ES would be located to minimize the adverse impact of the size of the shaft pillar and maximize the future utility of the shaft. If the shaft pillar was excessively large, its location could be detrimental to repository development.

3. ENVIRONMENTAL

Archaeological. The ES was to be located so that destruction of significant archaeological resources could be avoided.

Sites within 300 feet of archaeologic resources eligible for the National Register of Historic Places would be excluded. Sites more than 1500 feet from significant archaeologic resources would be ranked higher than sites less than 1500 feet away. Sites remote from archaeologic resources would be ranked highest.

Biological. The ES was to be located so that impact on biologic species-of-concern could be mitigated without schedule delay.

Sites which would lead to destruction of Mojave Fishhook cacti would be ranked low. Sites where none of these cacti were located would be ranked higher. Sites which would lead to destruction of Desert Tortoises or their habitats would be avoided.

Effluent and Emissions. The ES was to be located so that effluent and emissions could be contained or controlled as required.

Sites where drilling muds, cuttings, muck, sewage, etc. could not be contained would be excluded. Sites where excess water from dewatering could not be controlled would be excluded. Sites where road paving would delay the schedule would be ranked low unless dust control could be achieved. Sites for which containment of effluents, stabilization of muck piles, control of excess water and control of dust were achievable with the least short and long term impact would be ranked highest.

Reclamation. The ES was to be located so that all disturbed surface areas could be reclaimed to the extent required.

Sites would be ranked higher where removal of temporary surface facilities would be less difficult. Also ranked higher would be those sites where recontouring requirements and replacement of topsoil to maximize natural succession of vegetation would be less difficult.

4. NON-TECHNICAL

> **Land Use. The ES was to be located to minimize delays in obtaining a land use permit.**

Access across Bureau of Land Management land could require a Federal Land Policy and Management Act right-of-way permit for road widening and paving. Sites would be ranked according to current estimates of lead time for a BLM or Air Force Permit.

> **Pollution Control. The ES was to be located to minimize delays resulting from obtaining pollution control permits.**

A Prevention of Significant Deterioration fugitive dust Permit could be required if more than 20 acres (including roads) were disturbed. A National Pollutant Discharge Elimination System Permit could be required for dewatering contaminated effluent. Sites would be ranked by the permits required and by estimated lead times.

> **Archaeological Salvage. The ES was to be located to avoid delays resulting from the need for archaeologic salvage.**

The State Historic Preservation Officer must review and comment on actions affecting sites eligible for the National Register of Historic Places before DOE approval can be given. ES sites requiring permit action or consultation would be ranked according to the lead time required.

NTS Security. The ES was to be located to avoid compromising NTS security.

The only site access would be on the east from NTS or from the existing Yucca Mountain Ridge road.

C. SCREENING PROCESS

The above criteria provided the means to screen the Yucca Mountain exploration block for preferred areas in which the Exploratory Shaft could be located to meet the objectives. Four of the criteria were selected by the Committee to perform this screening operation to preferred areas. Two of these were Scientific: 1) Boundary set-back and 2) Distance to potentially adverse structure. Two criteria were Engineering: 1) Constructibility and 2) Adverse topography and slopes.

The two scientific criteria specify set backs from either the block boundary or the potentially adverse structures in the block. Figure 1 is a map of the block of interest from which the boundary set-back was applied. Figure 2 is a map of structures from which the potentially adverse structures criterion was

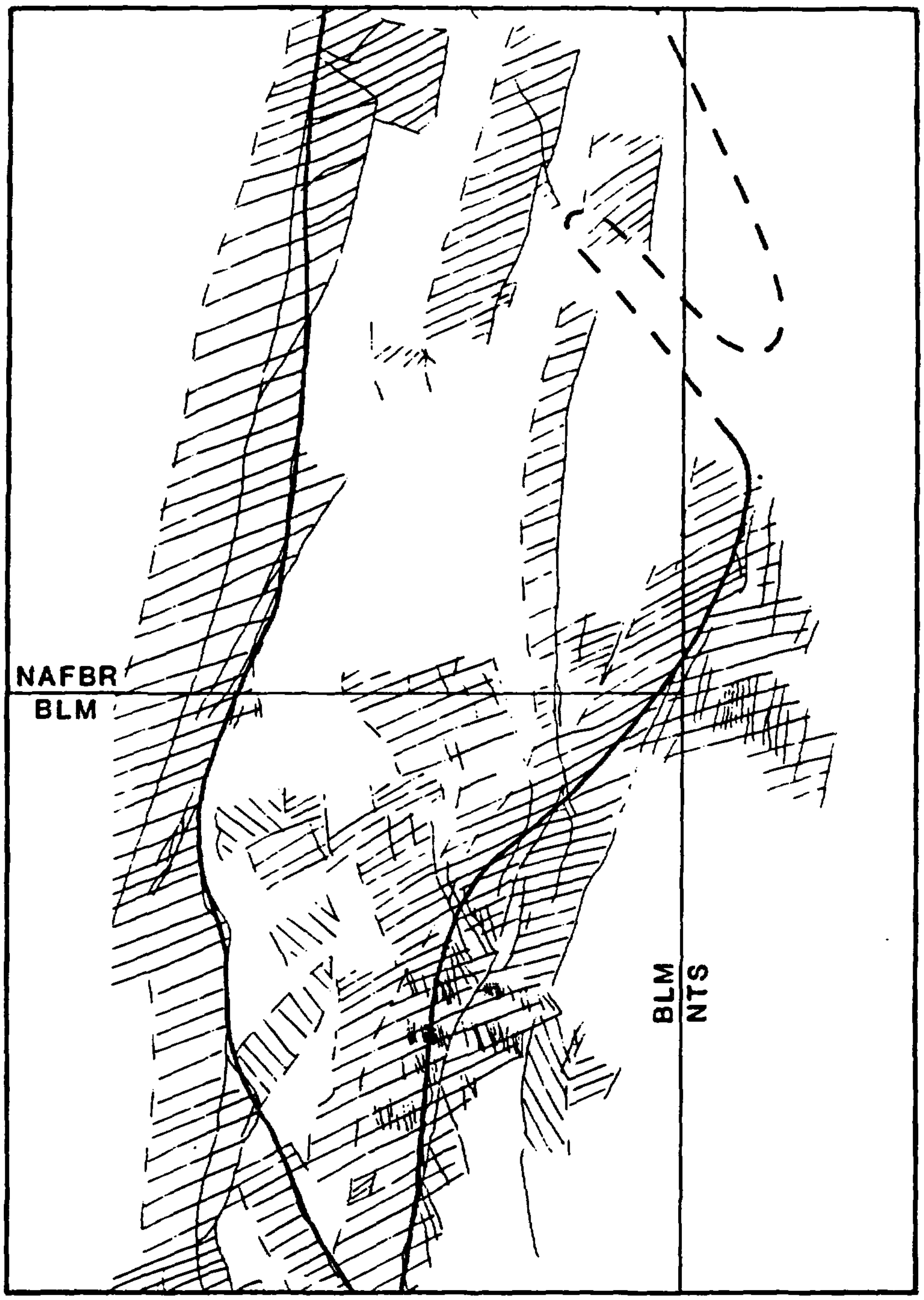

Figure 2. Potentially Adverse Structures at the Surface and at the 3200-Foot Depth

applied. In Figure 2, all structures shown were treated equally. To identify areas for the Exploratory Shaft using the two scientific criteria, it was necessary that the projection of both the block boundary and the potentially adverse structures be determined at the surface and at depth. Two depths were selected by the Committee for applying these criteria: 1600 feet and 3200 feet.

A reduced block of interest was obtained by applying the specified set backs from the surface boundaries (Figure 3). Then, using the potentially adverse structures, a surface set-back of 100 feet in the opposite direction of the dip of the potentially adverse structures was drawn as was a set-back into the hanging wall of the structure of 100 feet from the projection of the structures at the 3200 foot depth. This was an exclusion area. The area defined by this criterion also satisfied the constructibility criterion (Figure 4).

Adding to the exclusion area the preference for a set-back of at least 1000 feet but not more than 2000 feet from structures, several small areas of interest were obtained. In applying the 1000-foot and 2000-foot set-backs, the 1600-foot and 3200-foot depths were used as the reference elevations for the potentially adverse structure. The resulting areas were therefore greater than 100 feet at all elevations from a potential structure, at least 1000 feet and not greater than 2000 feet from a potential

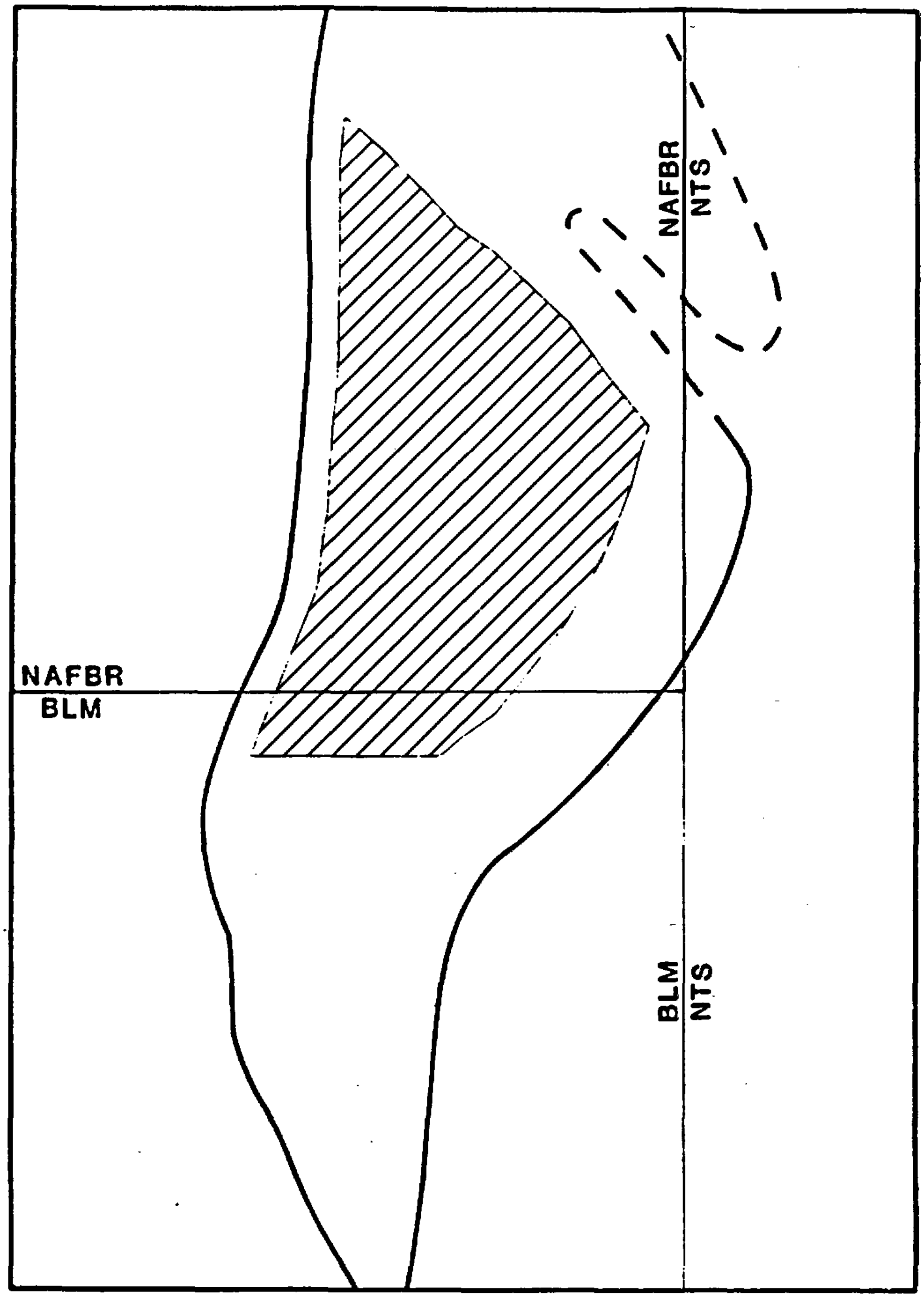

Figure 3. Area Defined by Boundary Set-Back Criterion

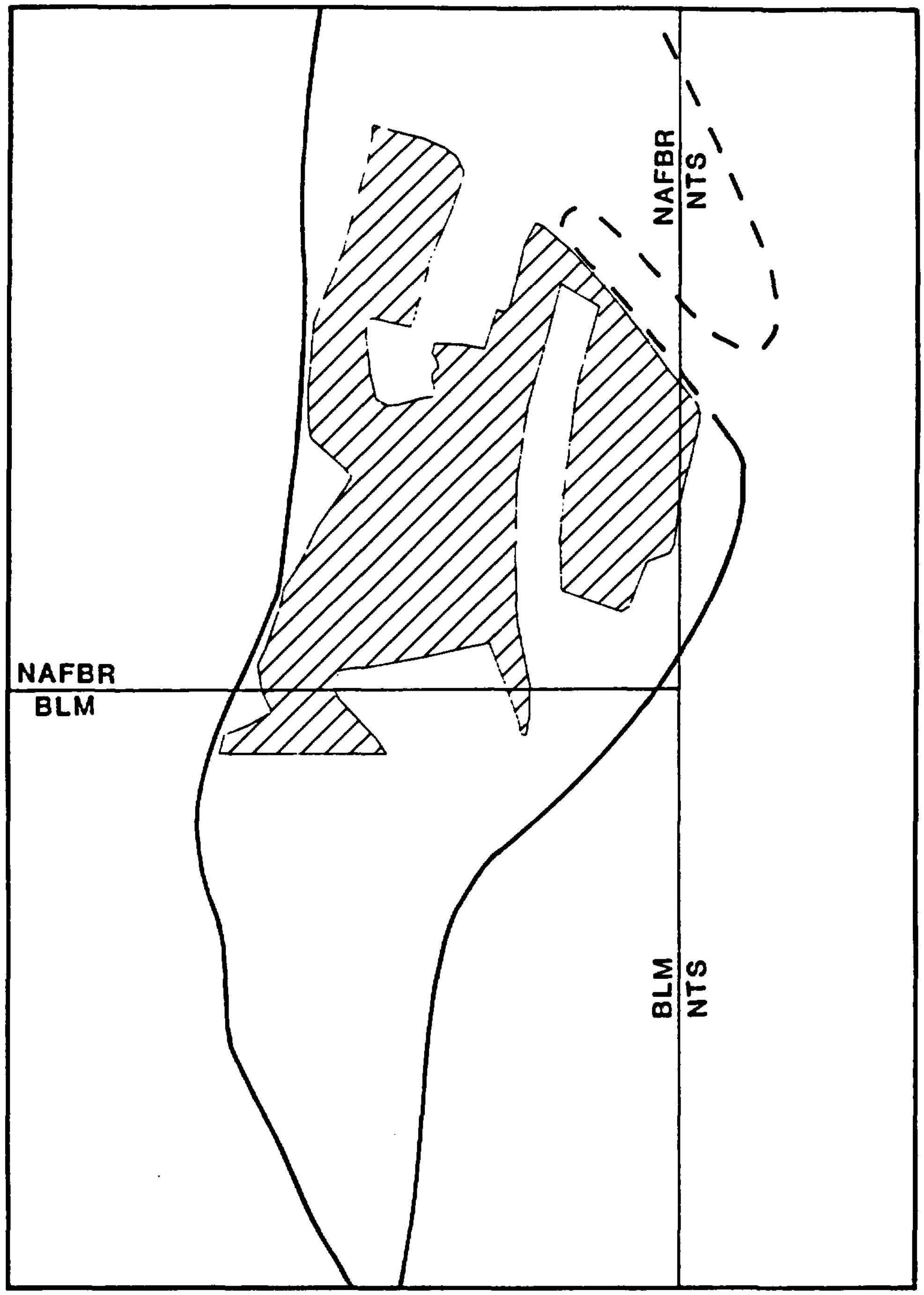

Figure 4. Areas Defined by 100-Foot Set-Back From Potentially Adverse Structures and by Constructibility

structure at all elevations, and set back from the exploration block's boundaries (Figure 5).

Independently excluding all areas of steep slopes or adverse topography, the Committee identifed several washes and the ridge top as the only acceptable areas for construction activities (Figure 6). The overlay of the areas defined by the two scientific criteria and the two engineering criteria produced five preliminary areas for the Exploratory Shaft (Figure 7). The remaining scientific, engineering, environmental, and nontechnical criteria were then applied to these areas, which remained unchanged. The resulting preferred areas are shown on a topographic map in Figure 8.

The Exploratory Shaft alternative sites within the preferred areas were identified by the engineering committee members, who conceptually designed into the areas the necessary mud pits, muck pile, storage areas, and road access. The five sites were inspected by the Ad Hoc Committee members on June 1, 1982. During the tour of the sites, the criteria were examined and determined to be adequate.

The locations of the preferred areas and the potential Exploratory Shaft sites are shown in Figure 9. The coordinates of the sites were based on conceptual design. Their refinement within the preferred areas would ultimately be based on the

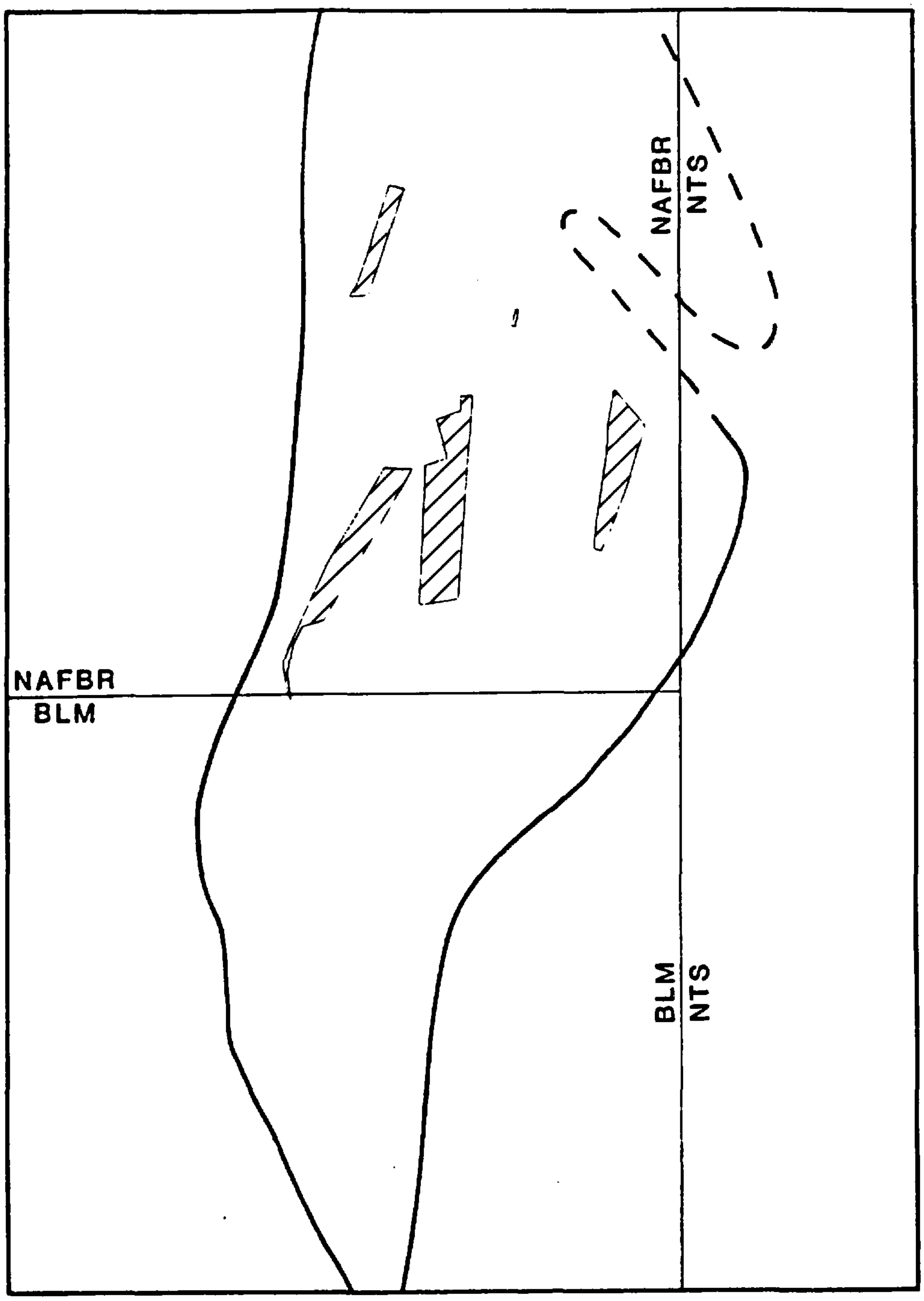

Figure 5. Areas Defined as 1000 to 2000 Feet From Potentially Adverse Structures

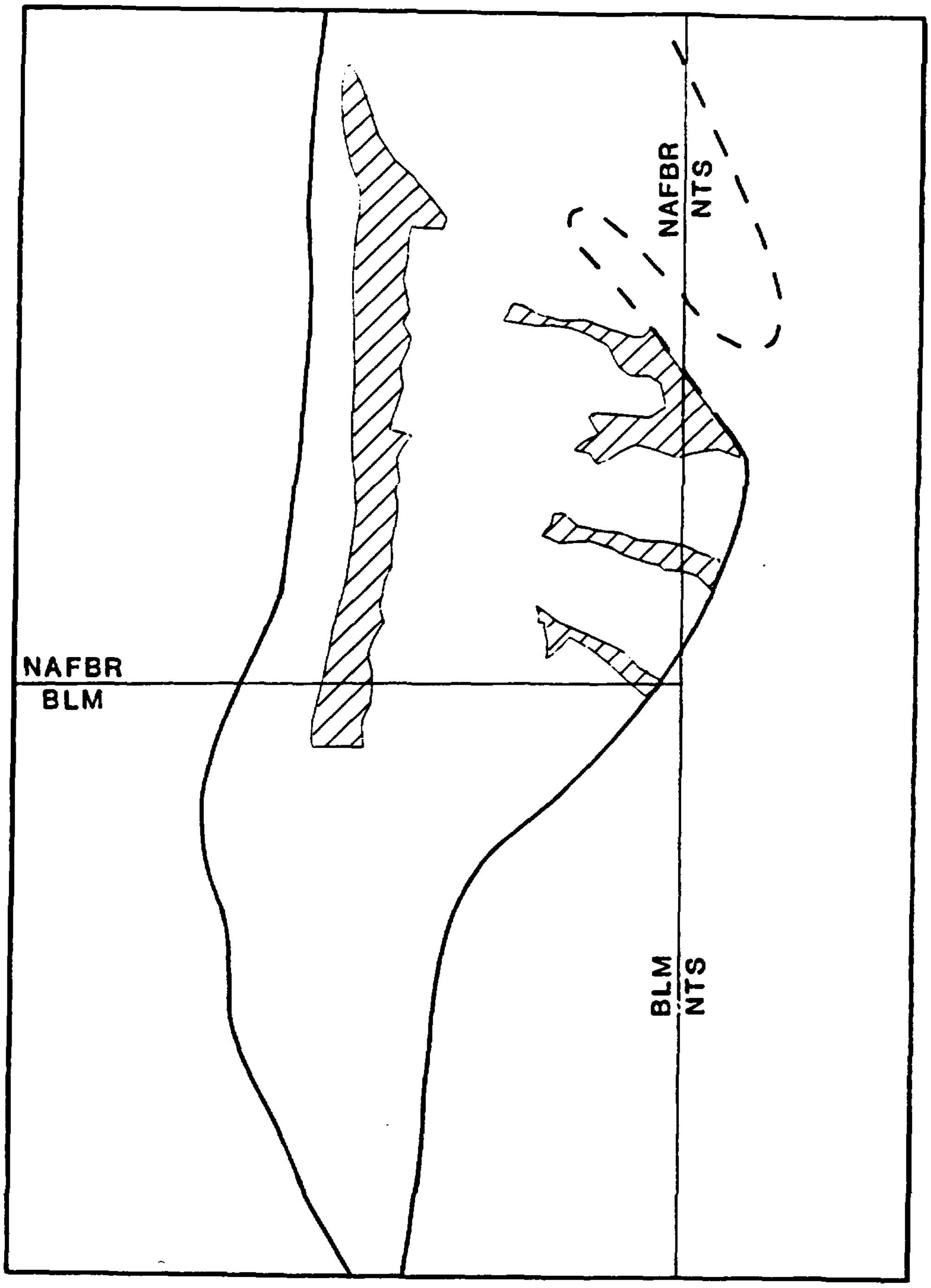

Figure 6. Areas Defined by Avoiding Adverse Topography

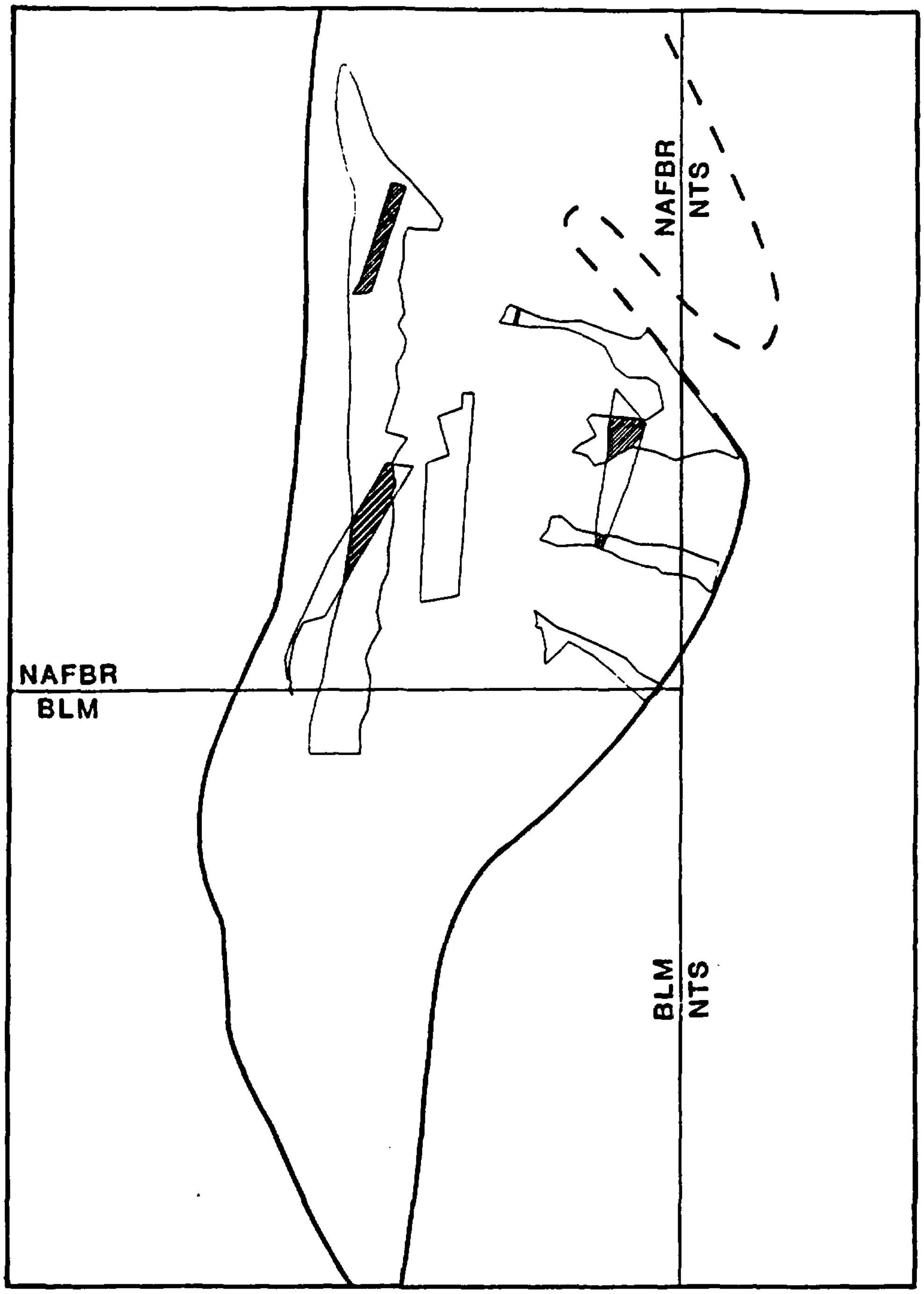

Figure 7. Overlay of Scientific and Topographic Preference Areas

Figure 8. Preferred Areas for the Exploratory Shaft

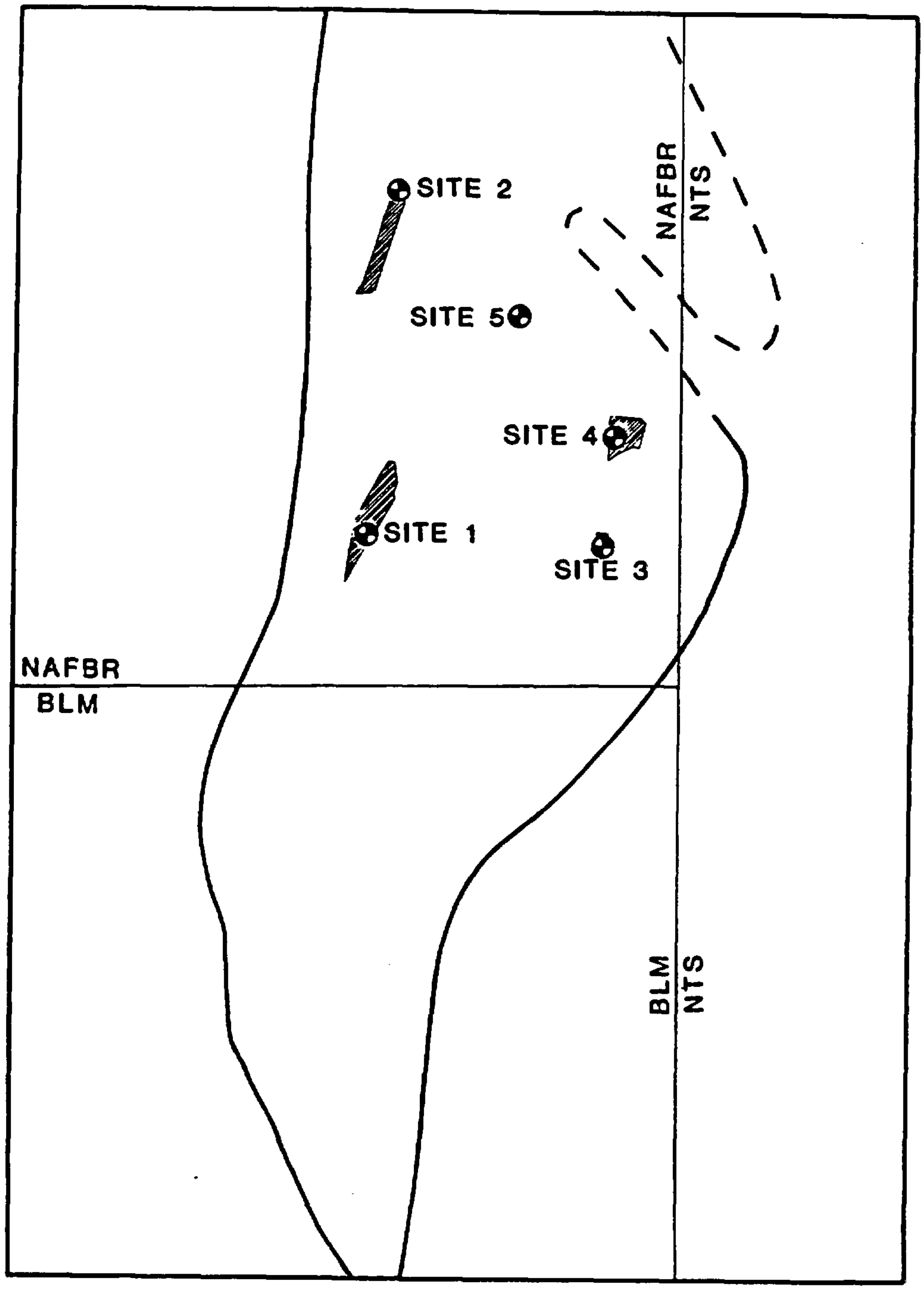

Figure 9. Preferred Areas and Site Alternatives for the Exploratory Shaft

architectural and engineering final design. The coordinates of the preferred areas and the sites are shown in Table 9.

D. EVALUATION SUBCRITERIA

After identifying the five sites, the next step for the Committee was to evaluate the performance of each site against the remaining criteria. Although four categories were defined initially, these were reduced to three as a result of the screening process. The categories were 1) Scientific, 2) Engineering, and 3) Environmental.

Several of the original criteria and subcriteria became nondiscriminating once the five sites were identified. Constructibility was eliminated as a subcriterion because it was an exclusionary criterion for the screening process; all five sites were selected to satisfy constructibility. Topography was also eliminated for the same reason. Biologic species were eliminated as a subcriterion because at none of the five sites were biologic species-of-concern evident. Land use was eliminated since all five sites were on Air Force land. The remaining nontechnical criteria, pollution control and archaeologic salvage, were combined with the definitions of the effluents and emissions and the archaeological subcriteria, respectively. Because of the locations of the five sites, there was no difference in the level of security of each relative to the NTS.

Table 9. Coordinates of Preferred Areas and Sites

VERTICES	NEVADA COORDINATE SYSTEM (feet) EAST	NORTH
AREA 1		
A	558857	764541
B	558703	763430
C	559565	764908
D	559528	764977
E	559609	765178
F	559541	765511
G	559442	765518
Site	559100	764300
AREA 2		
A	559768	770284
B	559173	768505
C	559099	768463
D	558834	768445
E	558960	768617
F	559196	769285
G	559331	769777
H	559520	770348
Site	559600	770300
AREA 3		
A	563008	764338
B	562987	764116
C	563101	764075
D	563221	764311
Site	563100	764100
AREA 4		
A	563245	766351
B	563178	765583
C	563610	765825
D	563728	765798
E	563850	766221
F	563781	766292
Site	563300	766000
AREA 5		
A	561597	767922
B	561671	768210
C	561716	768190
D	561646	767914
Site	561653	768046

The remaining criteria and subcriteria are listed below. A definition of each subcriterion is given.

1. SCIENTIFIC

This criterion addresses the objectives (a) Exploration from the shaft must be capable of accessing unsaturated and saturated target units to both confirm favorable conditions and to assess potentially adverse conditions; (b) Known areas of potentially adverse subsurface conditions must be avoided for shaft siting, but these areas must be accessible for testing from the shaft.

a. Subsurface Facilities in Good Pock. The relative ability to locate the ES where access can be provided to favorable rock conditions typical of the exploration block as a whole. Favorability includes relatively homogeneous target zones, minimal groundwater in-flow, adequate rock mechanical properties, and absence of faults and adverse fractures.

b. Vertical Thickness of Target Units. The relative ability to locate the ES where access to all target units can be optimized and thickness of the unsaturated target units can be maximized.

c. Distance to Potentially Adverse Structures. The relative ability to locate the ES where exploration of one or more potentially adverse structures within the repository block can be conducted. Preference will be given to those structures that might influence repository performance and to the potentially bounding structure in the unsaturated zone in Drill Hole Wash.

d. Volume Explored. The relative ability to locate the ES to explore the largest possible volume of the target units while remaining at least one drilling radius (about 2000 feet) away from the repository block boundary. The distance to Drill Hole Wash should be less than 2000 ft to allow exploration of the unsaturated zone beneath the wash.

2. ENGINEERING

This criterion addresses the construction assumptions of Safety and Technology: (a) the design and construction will incorporate established concepts and procedures that comply with current standards of the regulatory authorities; (b) the design concept and construction techniques will be based on established and proven technology. Care will be taken to assure that nothing will be done that would preclude use of the shaft as part of a future repository. This criterion also addresses the objective: Avoid surface areas where shaft construction would result in environmental effects that cannot be mitigated.

a. Construction costs. The relative ability to minimize the cost of constructing the ES, including site access, utility costs, depth to target units of interest, site preparation, and topographic constraints.

b. Flash flooding. The relative ability to locate the ES where the effects of flash flooding can be avoided or economically accommodated.

c. Waste rock disposal. The relative ability to locate the ES where the mining muck or drilling mud and cuttings can best be accommodated.

d. Repository compatibility. The relative ability to locate the ES where the future utility of the shaft in developing a repository can be maximized.

3. ENVIRONMENTAL

This criterion addresses the objective of avoiding unmitigable environmental impacts.

a. Archaeological. The relative ability to locate the ES where the destruction of significant archaeologic resources and where delays resulting from the need to salvage archaeologic resources can both be avoided.

b. Effluents and emissions. The relative ability to locate the ES where the consequences of failure to contain or control effluents and emissions can be minimized.

c. Reclamation. The relative ability to locate the ES where all disturbed surface areas can be reclaimed to the extent required.

d. Surface disturbance. The relative ability to locate the ES where the site extent and the topographic modifications required for site access and rights-of-way can be minimized.

E. WEIGHT OF CRITERIA AND SUBCRITERIA

To compute the Figure of Merit, each criterion and subcriterion was assigned a weight to reflect its importance in satisfying the objectives and assumptions. The consensus assignment of weight is shown in Table 10. Table 11 shows the weighting factors, the product of the weight of each subcriterion and the associated criterion, listed in order of their importance to the Committee.

F. PERFORMANCE COMPARISON

The Committee developed supplemental information for use in comparing the sites. Table 12 is a compilation of estimated distances, depths and thicknesses used for the scientific

Table 10. Weights of Site Selection Criteria and Subcriteria

CRITERIA	WEIGHT	SUBCRITERIA	WEIGHT
		Subsurface Facilities in Good Rock	0.30
1. Scientific	0.55	Vertical Thickness of Target Units	0.20
		Distance to Potentially Adverse Structures	0.25
		Volume Explored	0.25
		Subtotal	1.00
		Construction Costs	0.45
2. Engineering	0.30	Flash Flooding	0.10
		Waste Rock Disposal	0.20
		Repository Compatibility	0.25
		Subtotal	1.00
		Archaeological	0.25
3. Environmental	0.15	Effluents and Emissions	0.35
		Reclamation	0.20
		Surface Disturbance	0.20
Total	1.00	Subtotal	1.00

Table 11. Relative Weighting Factors for Site Selection Subcriteria

SUBCRITERIA	WEIGHTING FACTOR	CUMLATIVE WEIGHTING
Subsurface facilities in good rock	0.165	0.165
Distance to potentially adverse structures	0.138	0.303
Volume explored	0.138	0.441
Construction costs	0.135	0.576
Vertical thickness of target units	0.110	0.686
Repository compatibility	0.075	0.761
Waste rock disposal	0.060	0.821
Effluents and emissions	0.053	0.874
Archaeological	0.038	0.912
Flash flooding	0.030	0.942
Reclamation	0.030	0.972
Surface disturbance	0.030	1.002*

*Round-off error = 0.002.

Table 12. Estimated Site Dimensions (in Feet)

DIMENSION	Site 1	Site 2	Site 3	Site 4	Site 5
Distance from west bound (500-ft min at surface)	1,400	1,200	5,400	5,400	4,600
Distance from north bound (1,000 ft min at surface)	6,300	1,300	2,800	1,600	1,500
Distance from east bound (2,000 ft min at the surface)	5,200	7,500	2,100	2,400	4,700
Distance north of USW-H3 (4,000 ft min at the surface)	7,200	11,800	8,800	10,600	11,900
Radial distance to boundary	1,400 West	1,200 West 1,300 North	>2,000	1,600 North	1,500 North
Distance to adverse structures at 1600-ft depth	1,700 ft to hinge fault	1,200 ft to hinge fault, 1,300 ft to Drill Hole Wash	1,100 ft to N/S fault on east side	1,200 ft to N/S fault on east side	800 ft to N/S fault, 1,600 ft to Drill Hole Wash
Distance to adverse structures at 3,200-ft depth	1,800 ft south to faults	>2,000	1,000 ft east to fault swarm	1,200 ft east to fault swarm	500 ft east to N/S fault
Depth to top of unit					
Topopah Springs (densely welded)	530	560	220	280	250
Calico Hills	1,600	1,710	1,320	1,340	1,400
Bullfrog	2,130	2,410	2,170	2,230	2,150
Tram	2,680	2,860	2,670	2,680	2,650
Thickness of unit					
Topopah Springs (densely welded)	950	1,050	1,000	1,050	1,050
Calico Hills (above water table)	200	300	300	300	350
Bullfrog (mod. den. welded)	150	100	80	80	80
Tram	150	100	200	200	150

comparison. Information used for engineering and environmental comparisons is given below.

1. SUPPLEMENTAL INFORMATION

a. Repository Compatibility.

Because repository compatibility presents special conceptual design issues, one possible underground layout was used as a reference for evaluating the sites. Figure 10 shows the layout of a 2000-acre repository complex within the confines of the exploration block boundaries. This figure was developed using very preliminary information prior to modification by the USGS of the block boundaries to be used in the ES site screening. The boundary in Figure 10 is, therefore, slightly different from that in Figure 1. The layout was taken from a draft report describing preliminary repository configurations (SAND82-0436, Jan. 1982). The four shafts shown along the east/west central access corridor were located primarily by topographical constraints. Superimposed on the layout are the five alternative ES sites.

As the figure shows, none of the five sites approximated a shaft location in the preliminary configuration. It must be kept in mind, however, that the layout was an early configuration. It is much more likely that the repository layout could be modified to accommodate an ES location than that an ES would have to be abandoned because of incompatibility with a repository. It

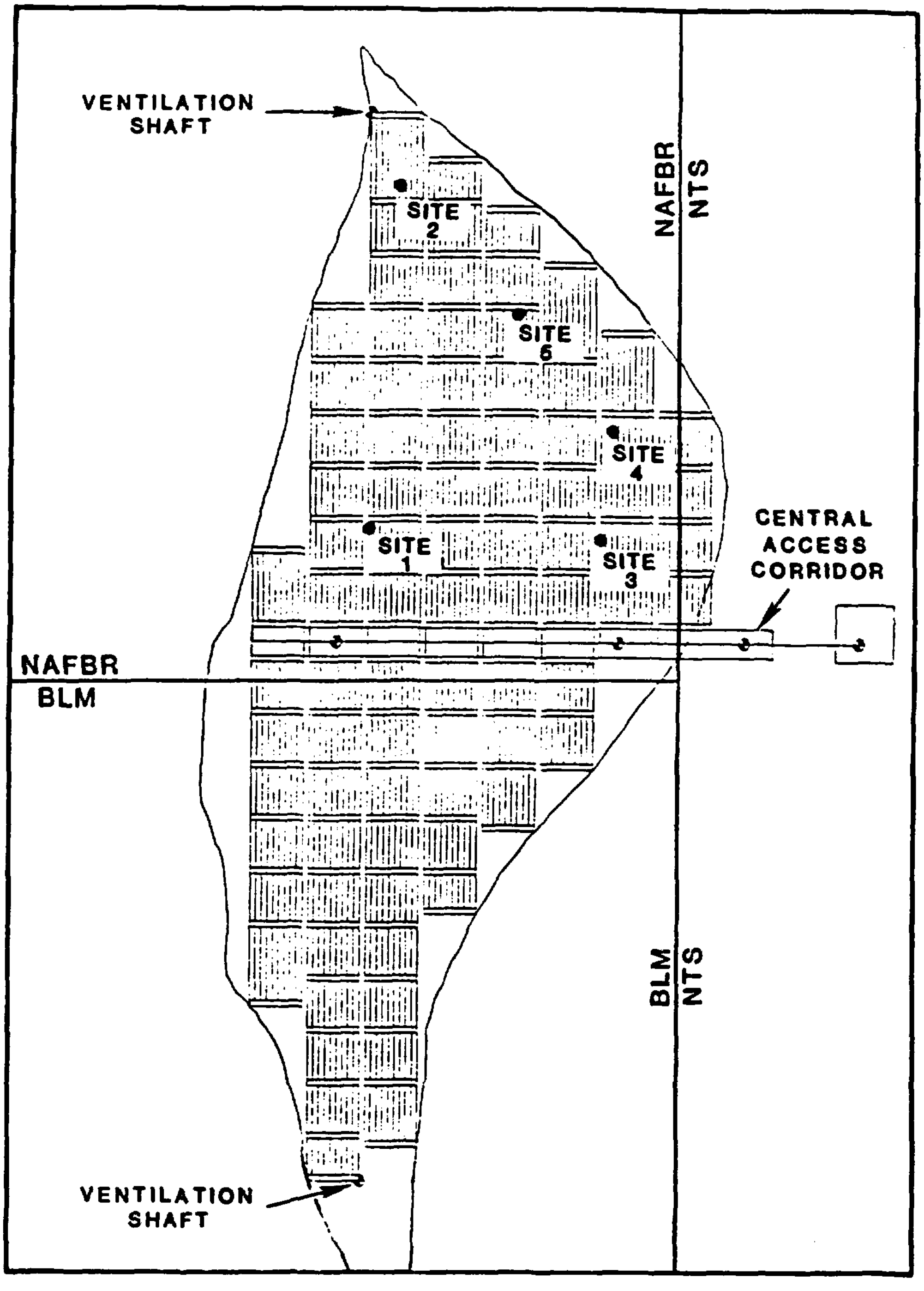

Figure 10. Possible Repository Layout and the Alternative Sites

should also be noted that a shaft the size of the ES could be utilized in a number of ways in later construction. It could become, for example, a ventilation shaft, an auxiliary access shaft, an emergency egress passage, or even a utility chase. It need not, therefore, be located along a main access corridor.

b. Engineering Considerations

Site 1. Rough cost estimates show the ES at this site would cost about $2.5 M - 3.0 M more than at the wash sites because of the long roads, the power line, the water line, and an additional 200 to 300 feet of shaft construction. Site preparation could require alluvium to be brought in from elsewhere for construction of mud pits or a muck pile berm. Site preparation cost could be in the order of $0.5 M to $1.0 M more than for two of the wash sites. Flash flooding would not be a concern. Waste rock disposal would require placing the muck at the head of a nearby wash, or building a large mud pit on top of the ridge. The shaft could be located on a central access corridor of a repository. For the conceptual layout shown in Figure 10, this would require relocating the corridor 1200 feet north. Such a move would place the repository surface facilities at the eastern end of Drill Hole Wash; although less than optimal, this could be accommodated.

Site 2. This site and Site 1 were similar, except for repository compatibility. A shaft here would be located near a possible ventilation shaft (see Figure 10) and would, therefore, appear to be very compatible with the layout. A very long ventilation tunnel would be required to link up with the shaft, causing the early-phase repository construction costs to increase dramatically.

Site 3. An ES at this wash site would cost about \$2.5 M - 3.0 M less than at the ridge sites. Also, site preparation would be less here because of the greater immediate space available and the adequacy of alluvium to allow grading the site and building mud pits (or a muck pile berm). Site preparation cost would be \$0.5 M to \$1.0 M lower than for three other sites. Site 3 was topographically more restrictive than Site 4. Flash flooding concerns relate to protecting the shaft site from flooding during short periods of high rainfall. Flooding of the shaft must be prevented and precautions must be taken to avoid washing out the mud pit or dispersing the muck pile. It would be relatively easy to provide adequate flood protection at this site. Waste rock disposal could require a short haulage distance to a muck pile. The repository compatibility would be the same as Site 1.

Site 4. This site, although similar to Site 3, would require minimum haulage for waste rock disposal. The potential function in a future repository would also be different. The shaft could be used as a ventilation shaft for early storage panels (see Figure 10). It could, therefore, be used to reduce the early construction costs. Since the ventilation shafts would have to be located on the ends of the storage panels, a shaft at this site would require shortening of some pictured panels.

Site 5. This site would be in a very narrow wash with an apparent lack of alluvial soil. Site preparation would be more involved and costly. Also, the "castle rocks" overhanging the north ridge could require removal or securing for safety reasons. Site preparation costs could be about $0.5 M to $1.0 M more than for the other wash sites. Flash flooding would be more difficult to protect against in the narrow wash. All waste rock would have to be hauled out of the shaft area. The repository compatibility would be the same as for Site 4.

c. Environmental Considerations

Site 1. There were no significant archaeological resources near this site, nor were there any sensitive biological species (Pippin, May 1982 and O'Farrell, 1982). The narrow ridgetop is steeply sloped. In this terrain, the ability to build a mud pit which would contain drilling effluents had not been demonstrated for Yucca Mountain. The only location for a muck pile would be at the head of a nearby wash. This area would be difficult to reclaim. The visual and biologic effects of uncontrolled effluents would be greater along the ridge. Severely limited availability of materials for drill pad and berm construction would lead to disturbance of a large surface area. The existing long access route would require more control over off-road driving of heavy equipment as well as more road paving. Because the shallow topsoil was also the only available construction soil, reclamation would require hauling in topsoil that was not similiar to that removed. Vegetation recovery would be impeded by wind and water erosion.

<u>Site 2</u>. This site, topographically similar to Site 1, had an extensive surface scatter of archaeological artifacts that had a relatively low probability of being significant (Pippin, May 1982). (The site significance had not been determined.) Existing surface disturbance resulting from soil removal to construct the USW H-5 drill pad was extensive and indicative of the scale of such disturbance to be expected for ES construction. All other comments about Site 1 apply here.

<u>Site 3</u>. This wash-bottom site was remote from archaeological resources and sensitive biologic species (Pippin, May 1982 and O'Farrell, 1982). A road accessed the site; paving would be required. The wash was already disturbed along the roadway, but the potential for excessive surface disturbance was less here than at any other site because there were no castle rocks to be removed and the wash was narrow enough to confine activities. The potential consequences of uncontrolled effluents were less here than at Sites 1, 2, or 5 for biologic species or visual effects. There were suitable locations for mud pit or muck pile construction which could be protected from flash flood damage. The reclamation potential was good.

Site 4. This site was in a broad, open wash remote from archaeological resources and sensitive biologic species (Pippin, May 1982 and O'Farrell, 1982). The openness of the wash could lead to excessive surface disturbance; however, the reclamation potential was good. The terrain provided suitable areas for mud pit or muck pile construction without flash flood problems. There was a good potential for controlling effluents; the consequences of uncontrolled effluents would be minor in this wash. Road construction would be required for only a short distance.

Site 5. This site was in a narrow, constricted, and steep wash. On the ridges above the wash bottom there were archaeological sites of minor importance which would be destroyed if the overhanging rock outcrops were removed (Pippin, May 1982). No sensitive species were present (O'Farrell, 1982). Construction of a mud pit or muck pile would require damming the flood channel partially or completely. The upstream drainage area was large and there was some doubt that long-term containment of effluents was achievable because of flash flood potential. New road construction would be required for a short distance, but total paving would be less than for the ridge-top sites. Visual and biologic effects of uncontrolled effluents and surface disturbance would be less than on the ridge top, but greater than at other wash sites. Reclamations should be relatively successful in the wash bottom, but impossible in the overhanging rocks; mud pit reclamation could require hauling away the cuttings and dried muds to avoid later dispersion by flash flooding. Surface disturbance in the wash bottom should be less than either of the other wash sites.

2. RELATIVE PERFORMANCE

The following assumptions were necessary in the evaluation process.

- All potentially adverse structures were treated equally.

- Drill Hole Wash (the northern boundary) was given preference for exploration because of the possibility that a repository in the unsaturated zone could extend across it.

- All units within the Topopah Springs, Calico Hills, Bullfrog, and Tram were considered homogeneous.

- The top of the Topopah Springs was considered to be at the top of the upper vitrophyre.

The relative performance of the alternatives was evaluated by the Committee. The performance measure of 1, 3, or 5 was assigned by each Committee member to each site based on its perceived ability to meet each criterion. The Committee required consistency of ratings. In two cases, consistency for a rating was not possible: this occurred for two Engineering criteria, construction costs, and waste rock disposal. In both cases, the Committee requested the members with engineering expertise to develop a consensus. The Committee also requested that the environmental ratings reflect only the environmental expertise. The average performance measures are shown in Table 13.

G. FIGURE OF MERIT

The merit values, derived by multiplying the performance measure by the weighting factor, are shown in Table 14. Therefore, the maximum possible merit value for the most important criterion was 0.83 and the minimum possible was 0.03 for the least important. The sum of the merit values for an alternative is the Figure of Merit. An FOM of 5.00 for an alternative would indicate highest favorability; an FOM of 1.00 would indicate lowest favorability. The completed FOM computation form is shown in Table 15. Site 4 had the highest FOM, 4.04. The remaining sites and their FOMs, in order of Preference, were: Site 5 (3.35), Site 3 (3.56), Site 2 (2.61) and Site 1 (2.22).

H. SITE 4 RECOMMENDATIONS

The NNWSI Technical Integration Group considered the Committee's recommendations of Site 4. The TIG consensus recommendation was that the NNWSI project proceed with developing the Exploratory

Table 13. Performance Comparison of Alternative Sites

SUBCRITERIA	PERFORMANCE MEASURES S_1	S_2	S_3	S_4	S_5
Subsurface Facilities in Good Rock	1.0	3.3	3.3	4.0	4.0
Vertical Thickness of Target Units	3.0	4.0	3.6	4.0	4.0
Distance to Potentially Adverse Structures	1.0	2.6	2.3	3.3	5.0
Volume Explored	2.0	1.0	4.0	4.6	4.3
Construction Costs	3.0	3.0	4.0	5.0	3.0
Flash Flooding	5.0	5.0	2.6	2.6	1.6
Waste Rock Disposal	2.0	2.0	3.0	4.0	1.0
Repository Compatibility	4.3	3.0	4.6	3.6	2.3
Archaeological	5.0	1.0	5.0	5.0	3.0
Effluents and Emissions	1.0	1.0	3.0	5.0	1.0
Reclamation	1.0	1.0	3.0	3.0	1.0
Surface Disturbance	1.0	3.0	5.0	1.0	3.0

Table 14. Merit Values of Alternative Sites for Each Subcriterion.

SUBCRITERIA	MERIT VALUES Max	S_1	S_2	S_3	S_4	S_5
Subsurface Facilities in Good Rock	0.83	0.17	0.55	0.55	0.66	0.66
Vertical Thickness of Target Units	0.55	0.33	0.44	0.40	0.44	0.44
Distance to Potentially Adverse Structures	0.69	0.14	0.36	0.32	0.46	0.69
Volume Explored	0.69	0.28	0.14	0.55	0.64	0.59
Subtotal	2.76	0.92	1.49	1.82	2.19	2.38
Construction Costs	0.68	0.41	0.41	0.54	0.68	0.41
Flash Flooding	0.15	0.15	0.15	0.08	0.08	0.05
Waste Rock Disposal	0.30	0.12	0.12	0.18	0.24	0.06
Repository Compatibility	0.38	0.32	0.23	0.35	0.27	0.17
Subtotal	1.51	1.00	0.91	1.15	1.27	0.69
Archaeological	0.19	0.19	0.04	0.19	0.19	0.11
Effluents and Emissions	0.27	0.05	0.05	0.16	0.27	0.05
Reclamation	0.15	0.03	0.03	0.09	0.09	0.03
Surface Disturbance	0.15	0.03	0.09	0.15	0.03	0.09
Subtotal	0.76	0.30	0.21	0.59	0.58	0.28
FIGURES OF MERIT	5.03*	2.22	2.61	3.56	4.04	3.35

*Round-off error = 0.03.

Table 15. Figure of Merit Evaluation for Exploratory Shaft Site Alternatives

MAJOR CRITERIA	WEIGHT	SUBCRITERIA	WEIGHT	WEIGHTING FACTOR	PERFORMANCE MEASURE S_1	S_2	S_3	S_4	S_5	MERIT VALUES S_1	S_2	S_3	S_4	S_5
		Subsurface Facilities in Good Rock	0.30	0.165	1.0	3.3	3.3	4.0	4.0	0.17	0.55	0.55	0.66	0.66
Scientific	0.55	Vertical Thickness of Target Units	0.20	0.110	3.0	4.0	3.6	4.0	4.0	0.33	0.44	0.40	0.44	0.44
		Distance to Potentially Adverse Structures	0.25	0.138	1.0	2.6	2.3	3.3	5.0	0.14	0.36	0.32	0.46	0.69
		Volume Explored	0.25	0.138	2.0	1.0	4.0	4.6	4.3	0.28	0.14	0.55	0.64	0.59
							Subtotal			0.92	1.49	1.82	2.19	2.38
		Construction Costs	0.45	0.135	3.0	3.0	4.0	5.0	3.0	0.41	0.41	0.54	0.68	0.41
Engineering	0.30	Flash Flooding	0.10	0.030	5.0	5.0	2.6	2.6	1.6	0.15	0.15	0.08	0.08	0.05
		Waste Rock Disposal	0.20	0.060	2.0	2.0	3.0	4.0	1.0	0.12	0.12	0.18	0.24	0.06
		Repository Compatibility	0.25	0.075	4.3	3.0	4.6	3.6	2.3	0.32	0.23	0.35	0.27	0.17
							Subtotal			1.00	0.91	1.15	1.27	0.69
		Archaeological	0.25	0.038	5.0	1.0	5.0	5.0	3.0	0.19	0.04	0.19	0.19	0.11
Environmental	0.15	Effluents and Emissions	0.35	0.053	1.0	1.0	3.0	5.0	1.0	0.05	0.05	0.16	0.27	0.05
		Reclamation	0.20	0.030	1.0	1.0	3.0	3.0	1.0	0.03	0.03	0.09	0.09	0.03
		Surface Disturbance	0.20	0.030	1.0	3.0	5.0	1.0	3.0	0.03	0.09	0.15	0.03	0.09
							Subtotal			0.30	0.21	0.59	0.58	0.28
						FIGURES OF MERIT				2.22	2.61	3.56	4.04	3.35

Shaft at Site 4 subject to the three following recommendations and one caveat.

1. USGS should prepare detailed surface geologic maps for the nearby vicinity of each of the five candidate exploratory shaft sites identified. If surface joint densities are significantly higher at the recommended site than at the other sites, the site selection should be reviewed in light of this new data.

2. USGS should implement a geophysical evaluation (which could range from a review of available data to acquisition and interpretations of new site specific data) to determine prior to drilling the preliminary borehole, USW G-4, whether subsurface structure exists beneath the washes located on the eastern flank of Yucca Mountain and, specifically, if subsurface structure exists beneath the proposed site which could compromise the constructibility or characterization utility of the ES.

3. If recommendation two above could not be completed prior to drilling USW G-4 on a schedule consistent with the accelerated ES schedule and a decision were made to drill prior to completing two, then the objective of USW G-4 would be exploratory (that is, it would be necessary to determine the potential existence of structure) rather than confirmatory. The geophysical evaluation should still completed.

4. The ultimate use of the Exploratory Shaft in the potential repository could not be defined because of the lack of a conceptual design for a Yucca Mountain repository. Therefore, the proposed site might be mislocated from the standpoint of long-term optimal utilization of the Exploratory Shaft as an integral part of a potential Yucca Mountain repository.

I. CONCLUSION

The unanimous conclusion of the Ad Hoc TOC Committee was that the NNWSI Exploratory Shaft should be constructed at Site 4, on the eastern flank of Yucca Mountain. The site is in Coyote Wash near the mouth of Drill Hole Wash. The coordinates for the site are 766000N by 563300E in the Nevada Coordinate System. The preferred area in Coyote Wash is only 600 ft by 780 ft at the maximum dimensions, with Site 4 only 60 ft from the western edge of the area. Therefore, caution was advised in any minor relocation resulting from architectural/engineering design considerations to avoid moving the site outside the preferred area.

GLOSSARY

A&E - Architectural Engineering

AHWG - Ad Hoc Working Group

BLM - Bureau of Land Management

DOE - U. S. Department of Energy

ES - Exploratory Shaft

FOM - Figure of Merit

LANL - Los Alamos National Laboratory

LLNL - Lawrence Livermore National Laboratories

MSHA - Federal Mine Safety and Health Act of 1977

NAFBR - Nellis Air Force Bombing Range

NNWSI - Nevada Nuclear Waste Storage Investigations

NRC - Nuclear Regulatory Commission

NTS - Nevada Test Site

OSHA - Occupational Safety and Health Act of 1970

SNL - Sandia National Laboratories

TIG - Technical Integration Group

TOC - Technical Overview Contractor

USGS - U. S. Geological Survey

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