EXPLORATORY SHAFT STUDIES - THE ROAD TO REASONABLE ASSURANCE

AT THE BASALT WASTE ISOLATION PROJECT

Harry Babad, Michael B. Arndt, George C. Evans
Rockwell Hanford Operations
P.O. Box 800
Richland, Washington 99352

ABSTRACT

A method for characterization planning and issue resolution aimed at providing reasonable assurance of site acceptability is presented in terms of the in situ test program planned for the Exploratory Shaft Facility at the Hanford Site. This paper also contains a summary description of the planned test program in the Exploratory Shaft Test Facility.

INTRODUCTION

Exploratory Shaft studies are a logical part of the overall process of studying potential repository sites. A sound site characterization program progresses logically from field and laboratory reconnaissance studies to more focused in situ testing and field studies. The characterization program is planned so that the Nuclear Regulatory Commission (NRC) will have reasonable assurance that the data and analysis to support licensability will be available.

The method used by the U.S. Department of Energy (DOE) for defining the in situ studies necessary to support the site characterization program is presented in this paper. The planning method described is based on a multiple-step process illustrated in Fig. 1. The key to any successful program is the definition of the applicability, quantity, and quality of data acquired from that test program to support fulfilling the repository program mission. A prerequisite to such a definition is the establishment of licensing and mission strategies, accompanied by the definition of performance measures for various subsystems and components of the repository. Such strategy must focus the data acquisition and interpretation activities on providing reasonable assurance that the near-field performance objectives of the repository will be met. This paper contains a summary description of the planned test program in the Exploratory Shaft Test Facility (ESTF)in the context of this methodology.

The Basalt Waste Isolation Project (BWIP) in situ test program in the ESTF is part of site characterization requirements. Development of an ESTF would involve drilling and lining two 183-cm- (72-in.-) inside diameter access shafts and the subsequent excavation of underground drifts and test chambers at the reference repository location at the Hanford Site. This facility will provide access to the Cohassett flow for geohydrologic and geomechanics in situ characterization. The process of shaft and drift construction will address practical questions related to shaft and drift constructibility, rock opening stability, in situ conditions, and groundwater and methane gas inflow.

THE NUCLEAR REGULATORY COMMISSION "REASONABLE ASSURANCE" CRITERION

The NRC, in 10 CFR 60[1], defines a process called Performance Confirmation. This process applies to the evaluation of the DOE program of tests, experiments, and analyses that will be conducted to evaluate the adequacy of information used to determine with reasonable assurance that the performance objectives for the period after permanent closure will be met. "Reasonable assurance," as defined in the "Statements of Consideration"[1], is a recognized measure that allows the NRC to make judgmental distinctions concerning quantitative data that has parametric uncertainties associated with it. The NRC expects that the information considered in a licensing proceeding will include the probability distribution function for the consequences from anticipated and unanticipated processes and events. Even if the calculated probability of meeting the NRC performance standards is high, that would not be sufficient for the NRC to have reasonable assurance; the NRC would still have to assess uncertainties associated with the models and data that had been considered. This involves qualitative and quantitative assessments. Thus, the NRC focus is on a determination that the quality of the evidence supports a finding that the NRC performance standards have been met. Areas where qualitative factors must be considered include the correctness of the models used to describe the physical systems, as well as conclusions as to the performance of the geologic repository and of particular barriers over the long period. Such analyses, as stated by the NRC[1], must largely be based on inference since there will be no opportunity to carry out test programs that simulate the full range of relevant conditions over the periods for which isolation must be maintained. The reasonable assurance criterion must then be used to define the required confidence level that the NRC performance objectives will be met. In practice, this means that modeling uncertainties will be reduced by projecting the behavior of repository systems from well-understood, simpler systems that conservatively approximate the system in question. Available data must be evaluated in light of accepted physical principles, and the NRC will have to be the judge of reasonable assurance.

THE U.S. DEPARTMENT OF ENERGY CHARACTERIZATION PLANNING AND ISSUE RESOLUTION METHODOLOGY

The proposed DOE process for characterization planning and issue resolution is illustrated in Fig. 1. A brief overview of that method is presented here and is discussed in more detail below. Planning begins by analyzing the NRC requirements[1], the EPA standard[2], and the DOE General Siting Guidelines[3] in terms of the present site specific data base. Based on these requirements and site-specific issues, the licensing strategy is defined. Performance measures and closure criteria are used to judge site characteristics against the regulatory criteria. Identification of the information needed to resolve the BWIP issues (and the data that would address those information needs), accompanied by development of strategies for test planning, continues the planning process. The next step is the development of test plans that fulfill the specified information needs. After completion of investigations, test results are analyzed to determine whether the performance measures are indeed satisfied and, therefore, whether closure of a given issue can be made. The process necessarily involves a concurrent review of the strategy by NRC that ensures the information needs address the issues in a satisfactory and comprehensive manner. The criterion for closure is the determination by DOE that the specific information obtained by testing provides reasonable assurance that the General Siting Guidelines[3] and NRC performance objectives. will be met.

APPLICABLE REQUIREMENTS

Requirements that will be applied to the in situ testing in ESTF are found primarily in the following sources:

- 10 CFR 60[1]
- 40 CRF 191[2]
- 10 CFR 960[3]

In preparing the General Siting Guidelines, the DOE used the NRC and EPA regulations as the starting point and augmented these requirements to provide general guidelines for the recommendation of sites for repositories for the disposal of high-level radioactive waste and spent nuclear fuel in geologic formations. In this paper only the DOE General Siting Guidelines[3] are used in the examples presented because the applicable NRC and EPA requirements are reflected therein. The sections of the DOE General Siting Guidelines[3] most directly applicable to testing in the ESTF include parts of both the preclosure and postclosure guidelines. These are identified and paraphrased below.

(a) Qualifying Condition (960.5-2-9...). The host rock must be of sufficient extent and thickness to accommodate repository operation. Rock strength characteristics must be sufficient to ensure safe repository construction and operation. The in situ characteristics of the rock must be such that engineering measures beyond reasonably available technology for construction are not required.

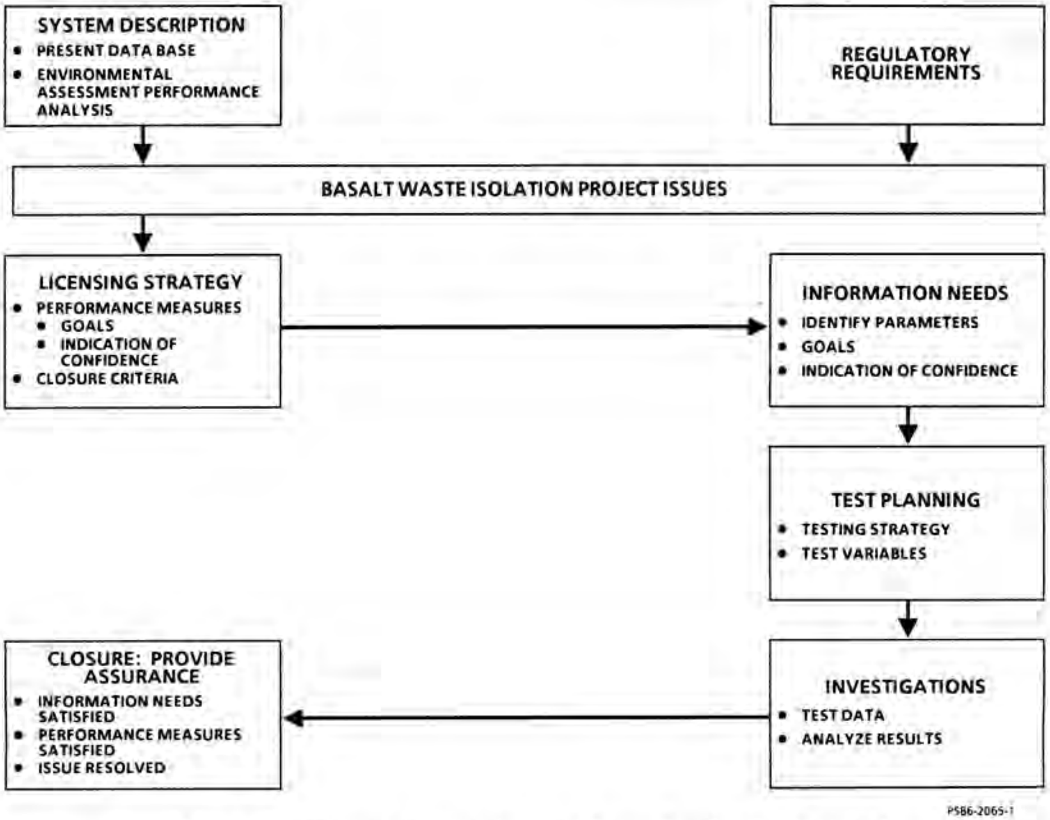

Fig. 1. Characterization Planning and Issue Resolution Methodology.

In addition to addressing areas of concern comparable to those summarized above, there are postclosure guidelines in the area of Geohydrology (960.4-2-2) and Rock Characteristics (960.4-2-3) aimed at assuring waste containment and isolation.

> (960.4-2-1(b)(4)). If disposal will occur in a saturated zone, the geohydrologic characteristics of the host rock and surrounding zones include low hydraulic conductivities and predominately downward or horizontal hydraulic gradients along the path of likely radionuclide travel between the host rock and the accessible environment.

> (960.4-2-3 and 960.4-2-7). The rock must be of sufficient thickness and extent to ensure isolation. In addition, the rock must have thermomechanical properties that ensure interactions between repository operation, heat generation, structural conditions (including effects of the tectonic environment), and groundwater do not significantly decrease the isolation potential of the host rock compared to prewaste emplacement conditions.

ISSUE DEVELOPMENT AND INFORMATION NEED IDENTIFICATION

The process of developing issues and defining their associated information needs related to site characterization was initiated as part of the development of the DOE Mission Plan[4]. The DOE Mission Plan[4] contains a hierarchy of issues and their associated information needs based on an analysis of the DOE General Siting Guidelines[3]. An issue, according to both DOE and NRC, is a general and site-specific technical or performance question that must be resolved prior to either site selection or the application for a license.

Draft issues appropriate to the nature of the activities in the ESTF are listed below.

Preclosure-Related Issues

What are the characteristics of the host rock and surrounding units that must be known to determine if construction, operation, and closure of a repository are feasible?

What are the hydrologic characteristics and conditions that must be known to determine if construction, operation, and closure of a repository are feasible?

What are the expected tectonic phenomenon and igneous activity that must be known to determine if construction, operation, and closure of a repository are feasible?

Postclosure-Related Issues

What are the present and expected characteristics of the geohydrologic setting that must be known to determine compatibility with containment and isolation?

What are the present and expected geomechanical characteristics that must be known to determine compatibility with containment and isolation?

What are the present and expected characteristics of the host rock and surrounding units that must be known to determine compatibility with containment and isolation?

What are the characteristics of future tectonic processes or events that must be known to determine if radiological releases are likely to be greater than those allowed by regulations?

Will the geologic repository at the reference repository location, including multiple natural and engineered barriers, isolate the radioactivity?

What characteristics and configurations of the underground facility contribute to containment and isolation?

These issues parallel the items discussed in the DOE Siting Guidelines[3]. Specifically the, information needs associated with these issues are comparable to those defined in Tables I and II, derived from the DOE General Siting Guidelines [3].

THE EXPLORATORY SHAFT TEST FACILITY TEST STRATEGY AND OBJECTIVES

In the analysis of the BWIP reference repository location (site)[5], the DOE makes a case that a determination of the safety and waste isolation requirements associated with an analysis of the rock characteristics and accompanying geohydrologic considerations, listed in the DOE General Siting Guidelines[3] can only be made by site characterization activities, specifically in situ testing in an ESTF. In situ testing is needed because it provides observations and measurements of geotechnical characteristics at the actual repository location. Were in situ testing in an ESTF not mandated by the Nuclear Waste Policy Act of 1982[6], analysis of the existing data base uncertainties would require it.

The objectives of the ESTF are to provide access to the Cohassett flow to perform in situ testing to obtain the information necessary for determining site characteristics, completing repository design, and assessing the performance of the repository. The Exploratory Shaft program initially focuses on shaft constructibility and safety considerations. A preliminary assessment of site geohydrology and geomechanics is obtained from the shaft prior to breakout and drift construction. As access to the host rock is achieved, the emphasis becomes focused on geologic, hydrologic, and geomechanics characterization, as well as continued demonstration of underground constructibility.

THE EXPLORATORY SHAFT TEST FACILITY PROGRAM

Construction

The first shaft will be blind-hole drilled to a depth of 1,034 m (3,393 ft), lined with a water-tight steel casing, and grouted into place. The shaft will have a 183-cm (72-in.) inside diameter and will be emplaced deep enough to permit shaft station breakout at the Cohassett flow interior. The dimensions and depth of the shaft concept are illustrated in Fig. 2.

During drilling, the shaft will be filled with drilling mud consisting of water, bentonite clay, and a biodegradable polymer. This will provide hydrostatic support to the shaft wall, lubricate and cool the drill bit and reamers, and carry rock cuttings (chips) to the surface by fluid circulation. The shaft will penetrate several aquifers, which may require sealing to prevent drilling mud losses. When drilling is completed, a steel liner will be

TABLE I. Preclosure Requirements, Data and Exploratory Shaft Testing Needed to Fulfill DOE Siting Guidelines on Rock Characteristic Requirements.

10 CFR 960 preclosure characteristic	Data needed	Test method(s)
Rock thickness	Borehole data	Core logging Borehole geophysics
	Exploratory Shaft Test Facility data	Geologic mapping Geophysical surveys
Rock lateral extent	Same as rock thickness	Same as rock thickness
Opening support requirements	In situ stress data	Overcoring
	Opening deformation data	Deformation monitoring Acoustic emissions monitoring
	Support characteristics/performance	Deformation monitoring Support monitoring
Opening maintenance requirements	Opening deformation data	Deformation monitoring Support monitoring
	Characteristics of the damaged rock zone	Mine-by test Deformation monitoring Geophysical tests
Rock thermal characteristics	Rock mass thermal conductivity	Heater test
	Rock mass thermal expansion	Heater test
Near-field faulting	Borehole data	Borehole data core logging Borehole geophysics Borehole hydrology
	Exploratory Shaft Test Facility data	Geologic mapping Geophysical surveys
Near-field shear zones	Same as near-field faulting	Same as near-field faulting
Other adverse structural features	Same as near-field faulting	Same as near-field faulting
Hydraulic properties	Vertical conductivity	Borehole tests Chamber test Cluster tracer test
	Horizontal conductivity	Same as vertical conductivity
	Storativity	Same as vertical conductivity
	Effective dispersivity	Same as vertical conductivity
	Groundwater geochemistry	Same as vertical conductivity
Isolation characteristics	Need for unique additional data	To be determined

"floated" into place. Following liner emplacement, a cement grout will be pumped into the annular space along the entire length of the borehole. This grouting step is aimed at maintaining liner stability and preventing water circulation between aquifers or into the repository horizon.

Boreholes will be drilled through specially designed portholes in the casing in order to assess the potential for high water inflow into the repository horizon during breakout. Porthole drilling also will be used to examine the effectiveness of the grout seal.

The initial breakout point (Fig. 2), is a drift 2.7 x 4 x 15 m (9 x 13 x 50 ft) cut into the rock of the Cohassett flow. The breakout area serves two purposes. First, it helps provide an initial verification that the basalts at depth are suitable for drift construction. Second, it provides working space to mobilize construction equipment. At the completion of drilling the first shaft, the shaft drill rig will be moved 152 m (500 ft) south where a comparable second shaft will be drilled. The second shaft will be drilled and completed in the same manner as the first shaft.

The Testing Program

The underground layout of the ESTF, shown in Fig. 3, provides a view of the test facility and defines the areas where specific testing will take place. The design is considered preliminary. Design reconfigurations and test strategy changes may take place as the studies progress.

Geologic Characterization: The emphasis in this part of the underground effort will be on mapping and evaluating the fracture characteristics of the Cohassett flow. Particularly significant are four horizontal exploratory boreholes that will be drilled (~305 m (1,000 ft)) into the flow interiors from the drifts. Fracture mapping of drift walls will take place concurrently with construction. The information gained from mapping and rock sample analysis will provide the project with information on in situ fracture distributions, fracture widths, and mineral infilling compositions and origins, thus helping to define the specific near-field geologic repository environment.

Hydrologic Characterization: Hydrologic tests undertaken within the ESTF will focus on

TABLE II. Postclosure Requirements, Data and Exploratory Shaft Testing Needed to Fulfill DOE Siting Guidelines on Rock Characteristic Requirements.

10 CFR 960 postclosure characteristic	Data needed	Test method(s)
Rock thickness	Borehole data	Core logging Borehole geophysics
	Exploratory Shaft Test Facility data	Geologic mapping Geophysical surveys
Rock lateral extent	Same as rock thickness	Same as rock thickness
Rock thermal characteristics	Opening deformation	Container hole heater test Heater test
	Characteristics of the damaged rock zone	Mine-by test Deformation monitoring Geophysical tests
Near-field faulting	Borehole data	Borehole data core logging Borehole geophysics Borehole hydrology
	Exploratory Shaft Test Facility data	Geologic mapping Geophysical surveys
Near-field shear zones	Same as near-field faulting	Same as near-field faulting
Other adverse structural features	Same as near-field faulting	Same as near-field faulting
Hydraulic properties	Vertical conductivity	Borehole tests Chamber test Cluster tracer test
	Horizontal conductivity	Same as vertical conductivity
	Storativity	Same as vertical conductivity
	Effective dispersivity	Same as vertical conductivity
	Groundwater geochemistry	Same as vertical conductivity
Worker safety	Air quality (including mine gas) Groundwater inflow Opening stability	Air monitoring Water balance monitoring Deformation monitoring Support monitoring Acoustic emissions monitoring

characterizing the Cohassett flow interior. Properties measured or calculated will include hydraulic conductivity, storativity, effective porosity, and possibly dispersivity and diffusion. Test methodology, duration, and success depend on the in situ conditions encountered at depth. At present the following four test approaches are planned.

• Chamber Tests. A large-scale test will be conducted of the hydraulic conductivity of a flow interior using a drift monitored by boreholes cored from within or adjacent to the drift.

• Cluster Tests. A borehole cluster room will be constructed between the access drift to the chamber test room. Cross-hole hydrologic and tracer tests will be used to measure hydraulic conductivity, effective porosity, and possibly dispersivity and diffusion within the interior of the Cohassett flow.

• Exploratory Borehole Tests. The boreholes will be cored and logged for fracture characteristics. These boreholes will then be used to measure hydraulic conductivity distributions in the four directions from underground drifts. This information will provide a better understanding of the areally distributed hydraulic conductivity within a basalt interior measured at right angles to the predominantly vertical fracture patterns of the flow interior.

• Other Borehole Tests. Many boreholes cored within the cluster area and chamber room and from the shafts themselves will be hydrologically tested. Plans include coring and testing in holes penetrating adjoining flow interiors and flow tops. Groundwater samples will be collected from boreholes penetrating adjoining flow tops. Hydraulic heads will also be monitored.

Modification to the above test approaches may take place as test strategies are refined. Directly observing the quantity and distribution of groundwater and gas inflow into the drifts may confirm the groundwater conceptual model developed to describe the behavior of the groundwater in the basalt flow interiors in the Exploratory Shaft.

Geomechanics Characterization: Geomechanics tests and monitoring will be performed within the ESTF. Concurrently, laboratory testing of basalt will be conducted to characterize its physical, mechanical, and thermal properties, in addition to supporting the evaluation of the in situ test results. These in situ and laboratory tests are important to determine if rock conditions are suitable for waste emplacement, isolation, and possibly retrievability. Rock mass properties and in situ conditions will be measured, and the performance of the engineered systems will be

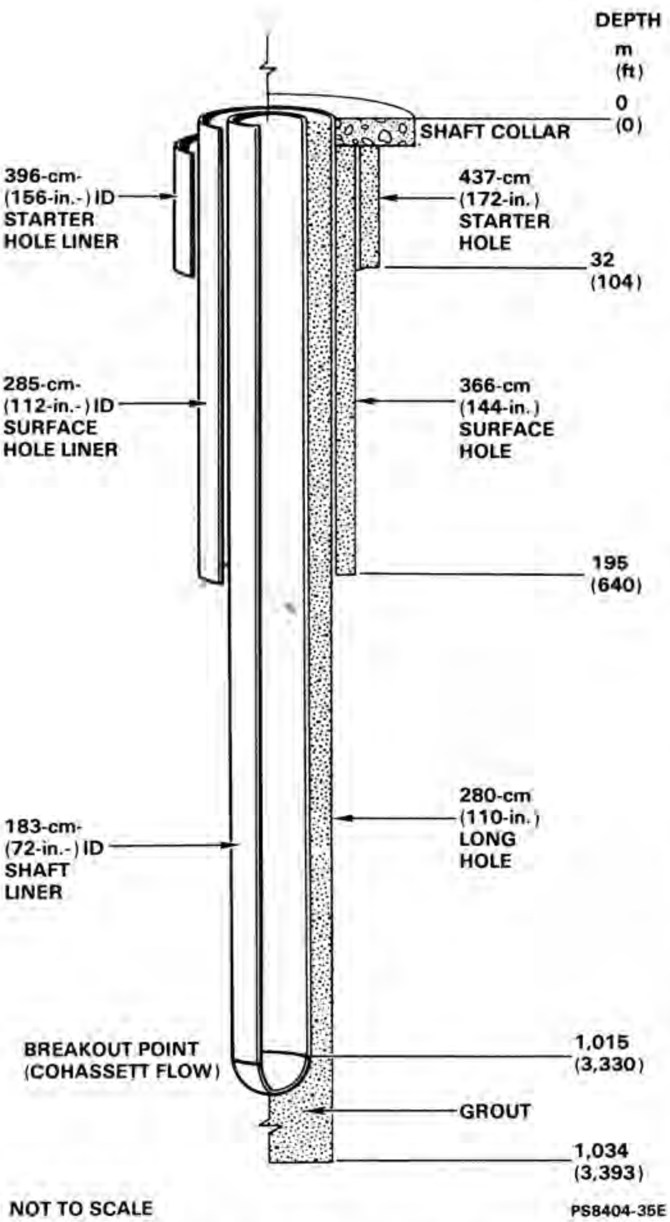

Fig. 2. Drilled Shaft Concept.

evaluated. These activities will provide the following information:

- Mechanical and thermal properties of the rock mass
- Magnitudes and orientation of in situ stress
- Nature and extent of construction-related disturbed rock zone
- Stability of waste-emplacement holes and waste-emplacement drifts during excavation and under condition of thermal loading
- Nature and extent of waste heat-related damaged rock zone
- Performance of rock (support systems).

Of particular importance in geomechanics characterization are the mine-by and heater tests (Fig. 3). These are tests in which the stability and performance of a prototypic repository room and waste-emplacement boreholes can be monitored. This monitoring will measure in situ conditions and elevated-temperature conditions resulting from heater testing. Geoengineering properties of the rock mass also will be obtained in these tests.

CONCLUSIONS

Exploratory Shaft studies are a logical part of the site characterization process that proceeds from field and laboratory studies to in situ testing. The approach used by BWIP for defining this part of the site characterization process is based on the multiple-step strategy defined in Fig. 1. The method begins by analyzing NRC requirements[1], the EPA standard[2], and the DOE General Siting Guidelines[3], in terms of the present site-specific data base. The definition of site-specific issues and the establishment of waste isolation subsystem and component performance measures (targets) by which site characteristics can be judged against the regulatory criteria follows. Identification of the information needed to resolve the issues (and the data required to address those information needs), accompanied by development of strategies for test planning continues the planning, process. The latter step develops test plans that fulfill the specified information needs. After completion of the in situ (as well as laboratory and field) investigations, the results will be analyzed to determine whether reasonable assurance is provided that the performance objectives of the repository will be met. This requires, as an intermediate step, a determination that the identified information needs are satisfied and that closure of a given issue can be made. In situ testing in the repository horizon has the greatest potential of providing such assurance because it is done under conditions most closely approximating those expected in the repository; therefore, the data obtained has the lowest uncertainty on which near-field repository performance will be projected.

In summary, this paper has described a process that will be used by the DOE to evaluate the potential for a repository in basalt. Determination of whether the site characterization data base supports the preclosure and postclosure rock characteristics and associated geohydrologic requirements of the DOE General Siting Guidelines[3] can thus be made. As a result of developing a process that resolves technical issues related to uncertainties about the site, the DOE could potentially provide reasonable assurance of meeting the EPA standard[2] and the NRC regulations[1].

Inquiries or requests for copies of this paper should be directed to:

Dr. H. Babad
Rockwell Hanford Operations
Basalt Waste Isolation Project
P. O. Box 800
Richland, WA 99352

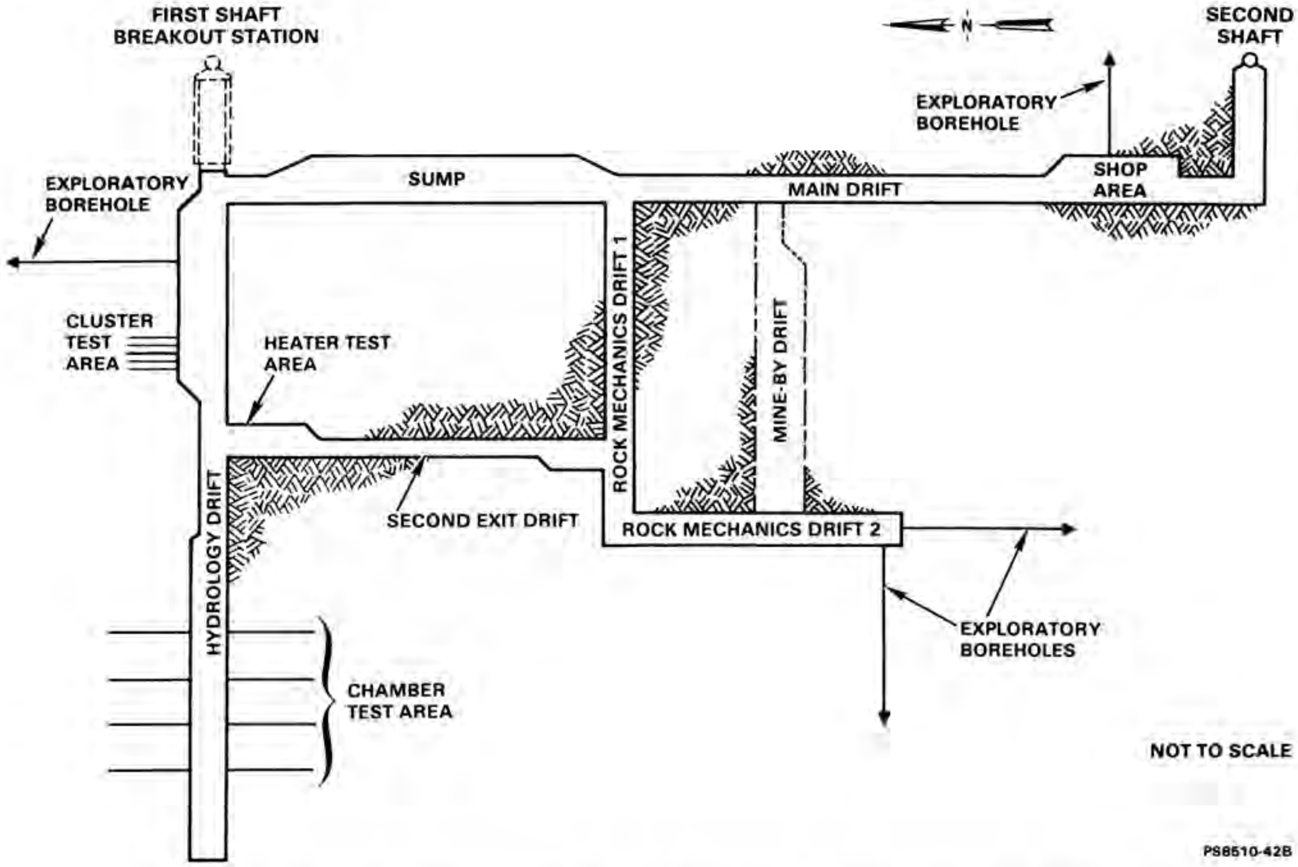

Fig. 3. Conceptual Arrangement of the Exploratory Shaft Underground Facilities.

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