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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
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IN SITU DESIGN VERIFICATION

STUDY PLAN 8.3.1.15.1.8

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ABSTRACT

The In Situ Design Verification Study comprises a set of four experiments that will be conducted in the Exploratory Studies Facility at Yucca Mountain, Nevada, as part of a program to assess the suitability of the site for disposal of nuclear waste. The four experiments, Evaluation of Mining Methods, Evaluation of Ground-Support Systems, Monitoring Drift Stability, and Air Quality and Ventilation, are intended to collect information related to construction of the experimental facility that will be useful in plans for design and construction of the proposed repository. This study plan comprises explanations of the purpose, objectives, and rationale of the study; descriptions of the experiments; a discussion of the application of results; and a schedule.

This work was performed under WBS 1.2.4.2.1.1.4 in accordance with the Sandia National Laboratories Quality Assurance Program Description.

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1.0 Introduction

Yucca Mountain in Southern Nevada has been selected as a potential repository for nuclear waste. The Yucca Mountain site characterization Project (YMP) personnel are responsible for evaluating the suitability of the site for this purpose. The program of site characterization includes excavation of an Exploratory Studies Facility (ESF) with a main test area at the proposed repository horizon, which is situated in a subhorizontal stratum of welded tuff approximately 300 m thick. One of the concerns that will be investigated in the ESF is the feasibility of constructing and maintaining the many miles of underground openings that would be needed in a repository. The In Situ Design Verification (Design Verification) study focuses on this concern.

The Design Verification study has been developed in response to two separate catalysts:

- In the design of the ESF, it was decided to investigate several geologic structures of interest at the repository horizon by excavating drifts rather than boreholes. This decision made available drifts that could be used to investigate the variability of the repository host rock and its effect on the constructability and performance of the openings.
- Needs for information to support the detailed design of the repository subsurface facilities were expressed during the performance allocation process and by reviewers of the Site Characterization Plan (SCP; DOE, 1988a). These needs include investigation and documentation of mining methods, mining equipment, ground supports, rock mass characteristics, opening performance, and numerous measurements pertinent to the design of ventilation systems.

As a result of these circumstances and needs, four experiments have been designed for the ESF: (1) an experiment to observe and evaluate mining methods, (2) an experiment to observe and evaluate the selection and installation of ground support systems, (3) an experiment to monitor the long-term behavior of drifts, and (4) an experiment to measure the parameters needed for design of the repository underground ventilation system.

The purpose of this study plan is to present the rationale and to describe plans for the experiments that compose the Design Verification study. This document includes as much detail as possible. In cases where alternatives have not yet been selected, the approaches that will be followed to make selections are given. Details that depend on the ground conditions actually encountered, such as exact quantities and locations of measurements, will not be finalized until the excavations occur. This flexible approach to experiment design is exemplified by the observational method described by Peck (1969). Put in context, the observational method calls for:

1. developing a preliminary design based on the limited data available,
2. establishing criteria for use during construction to judge whether the preliminary design is adequate,

3. identifying contingency plans, and, as work progresses,

4. evaluating the acceptability criteria and modifying the design, as necessary.

1.1 Objectives of the Study

The objectives of the Design Verification study are to:

- monitor and observe the long-term behavior of openings in a range of ground conditions in the repository host rock,
- observe and evaluate the construction of the ESF with respect to implications for repository constquction and performance, and
- collect information to be used in the design of ventilation systems in the repository underground facility.

1.1.1 Information to be Obtained

Following is a discussion of the information that needs to be obtained from each of the Design Verification study experiments. Much of the information required for this study will be gathered through observation of the construction and performance of the subsurface openings. It is intended that this study will take full advantage of data gathered in other facets of the site characterization effort. Data that will be used in this study but gathered as part of other activities include:

- construction records kept by the ESF architect/engineer (A/E) and constructors,
- data on performance of openings gathered in other experiments,
- ventilation parameters monitored to ensure worker health and safety in the ESF, and
- geotechnical mapping of ESF drifts to include faults, fracture density, fracture orientation, infill minerals, infill type and thickness and other rock structural characterization data gathered in geologic mapping activities (SCP Section 8.3.1.4.2.2.4).

1.1.1.1 Evaluation of Mining Methods Experiment

Records will be made of the methods and equipment used to excavate the main accesses and the drifts of the ESF. The resulting excavated spaces will be described in terms of conformance with design specifications and the extent of observable excavation effects on the surrounding rock. The data will be correlated with local ground conditions described by rock mass quality using the NGI-Q system (Barton et. al., 1974) and the CSIR-RMR system (Bieniawski, 1973). Mining methods may include both mechanical mining and drill and blast, and will be refined with the intent of developing procedures for excavating repository openings.

1.1.1.2 Evaluation of Ground Support Systems Experiment

Records will be made of the ground supports installed in the drifts, including installation procedures and equipment performance and will be correlated with rock mass quality. The types of ground supports used at any given location may be based in part on empirical design methods based on rock mass classification; the parameters measured to classify the rock mass quality will also be recorded. The load-deformation relationships and capacities of some ground supports will be measured. In situ loads on some supports will be monitored, but performance will primarily be assessed in terms of displacements and usability of the supported openings.

1.1.1.3 Monitoring Drift Stability Experiment

Cross-drift convergence of the excavated surfaces will be monitored throughout the ESF, and at several drift intersections. Movement within the rock surrounding the openings will be monitored at selected locations using borehole extensometers. Records will be kept of rockfalls and maintenance. Emphasis will be placed on the displacement of the openings over the long term and identification of excessive movement or sudden shifts that might jeopardize the usability of the opening.

1.1.1.4 Air Quality and Ventilation Experiment

Rates of emanation of radon gas from both the rock mass and excavated tuff waste will be derived from measurements of the radioactive radon daughter products in the air. The occurrence of other gases may also be characterized, as needed. Measurements of the particulate concentrations and character, associated with the mining and operation of the ESF, will be conducted in the ventilation air. Airflow, pressure, temperature and humidity will be measured as part of heat balance surveys and to determine airway friction factors. Rock temperature changes also will be measured to evaluate the thermal exchange coefficients for convective and radiative heat flow form the drift walls.

1.1.2 Use of Results

The intent of this study is to document the process of constructing the ESF, observe the results, and draw conclusions regarding the feasibility of constructing and maintaining repository-scale openings in the host rock. Results of the Design Verification study experiments will be used to:

- demonstrate whether repository-scale openings can be constructed, supported, and maintained in the host rock safely and using reasonably available technology;
- help predict the long-term behavior of repository openings;
- support evaluations of public radiological health and safety;
- support construction scheduling, cost estimating, and operations planning; and
- make recommendations for designing, constructing, and maintaining the repository subsurface facilities.

The uses of the results of each experiment are given briefly below; specific applications of test results are discussed in Section 5.0.

1.1.2.1 Evaluation of Mining Methods Experiment

The performance of the mining methods used in the ESF and the experience gained during construction will form the basis for recommendations about repository construction. Constructability of repository-scale openings in various ground conditions will be demonstrated by the excavation of the ESF. Current planning is based upon mechanical mining using full face tunnel boring machines (TBMs) for the relatively long, straight excavations (ramps, main accesses) and partial face machines (roadheaders, and mobile miners) for shorter drifts, cross cuts and ramps where higher mobility and maneuverability are required. It is possible that conventional drill and blast mining will also be used for short drifts, cross cuts and service alcoves. Records on performance of the different mining methods will be used for repository planning.

1.1.2.2 Evaluation of Ground Support Systems Experiment

The documentation of ground support and correlation with rock mass quality will provide the basis for comparison of support performance and support design using empirical methods. Empirical design for support of repository excavations can be based on modifications of the rock mass classification system that sensitize it to the local environment.

1.1.2.3 Monitoring Drift Stability Experiment

Monitoring drift stability will provide part of the basis for assessing the long-term performance of the repository drifts. The monitoring will evaluate long-term stability of repository drifts in a variety of ground conditions and provide verification that time-dependent deformation of the repository host rock is not significant. The data will provide a basis for specifications to assess opening stability, will help to identify any impending instabilities, and provide quantitative measures to evaluate the effects of mining methods and the effectiveness of the ground support systems. Finally, techniques for monitoring drift stability for possible use in the repository will be developed.

1.1.2.4 Air Quality and Ventilation Experiment

Results of this experiment will be used to design the ventilation systems for the repository underground facilities. The rate of radon emanation from the rock mass, which will be measured as part of this experiment, will be used to quantify estimates of total radioactive release rates. Heat balance measurements in ventilation air will be used to analyze the results of the In Situ Thermomechanical Properties study (SCP activity 8.3.1.15.1.6).

Dust generation is a potentially significant problem during construction and operation of the ESF and the repository because of several reasons:

- the relatively high silica content of the rhyolitic tuff rocks will require dust levels to be very low to meet health and safety regulations,
- the constraints to minimize water use in the repository may impact one of the primary dust suppression techniques, and
- the planned use of mechanical mining will tend to produce higher dust levels than conventional drill and blast mining.

Mitigation of dust effects at the face area is a primary problem in longwall coal mining operations where ventilation air volumes are restricted by long drift lengths. Similar problems will occur in the face areas of very long ESF and repository tunnels using ducted ventilation. The use of dust collection systems is practiced on TBMs and will be required for this application.

Dust sampling will be required to quantify the degree of the problem and assess the success of dust suppression systems. New regulations proposed by MSHA will also require characterization of diesel particulates. Characterization of diesel particulates is also necessary because dust concentration effects the extent to which radon daughters plate out on drift walls as opposed to being released from the repository in ventilation air.

1.2 Justification of Information to be Obtained

The need for the information to be obtained in this study can be demonstrated either in terms of the issues hierarchy, which was created to address regulatory requirements, or directly in terms of regulatory requirements. Both approaches are followed here.

1.2.1 Resolution of Performance and Design Issues

In the YMP, the performance-allocation process identifies performance measures and information needs required to resolve design and performance issues identified in the issues hierarchy. A general description of the performance-allocation approach is provided in Section 8.1 of the SCP. Section 8.2 of the SCP comprises descriptions of the key issues, the subordinate performance and design issues, supporting information needs, and strategies for issue resolution. The Design Verification study is a part of the thermal and mechanical properties portion of the site program. The study is specifically described in SCP Section 8.3.1.15.1.8.

The information needs addressed by the Design Verification study, listed in Table 1.2.1-1, are encompassed by Key Issues 1, 2, and 4, which are concerned with postclosure repository performance, preclosure radiological safety, and preclosure repository performance, respectively. Following is a discussion of how the Design Verification study will contribute to resolution of these issues.

Within Key Issue 1, Design Issue 1.11 (SCP Section 8.3.2.2) addresses the ability of the repository and the repository engineered barriers to satisfy postclosure requirements. One requirement associated with resolution of this issue is to establish design concepts for layout of the underground facility that include flexibility to accommodate site-specific conditions (Information Need 1.11.3, SCP Section 8.3.2.2.3). This requirement will be addressed by the Design Verification study in an experiment that matches ground supports to ground conditions using an empirical, rock-mass classification system, which has been adapted to site-specific conditions and requirements.

A second requirement of Design Issue 1.11 is to establish water usage constraints during repository construction (Information Need 1.11.4, SCP Section 8.3.2.2.4). The quantities of water used in excavation will be monitored as part of the Design Verification study.

Table 1.2.1-1 Information Needs Addressed by the In Situ Design Verification Study.

Information Need	Title	SCP Section
1.11.1	Site characterization information needed for design	8.3.2.2.1
1.11.3	Design concepts for orientation, geometry, layout, and depth of the underground facility to contribute to waste containment and isolation, including flexibility to accommodate site-specific conditions	8.3.2.2.3
1.11.4	Design constraints to limit water usage and potential chemical changes	8.3.2.2.4
1.11.5	Design constraints to limit excavation-induced changes in rock mass permeability	8.3.2.2.5
2.1.1	Site and design information needed to assess preclosure radiological safety	8.3.5.3.1
2.2.1	Determination of radiation environment in surface and subsurface facilities resulting from natural and man-made radioactivity	8.3.5.4.1
2.4.1	Site and design data required to support retrieval	8.3.5.2.1
2.4.2	Determination that access to the waste emplacement boreholes can be provided throughout the retrievability period for normal and credible abnormal conditions	8.3.5.2.2
2.7.1	Determination that the design criteria in 10 CFR 60.131-60.133 and any additional appropriate design objectives pertaining to radiological protection have been met	8.3.2.3.1
4.2.1	Site and performance assessment information needed for design (regarding nonradiological health and safety of workers)	8.3.2.4.1
4.4.1	Site and performance assessment information needed for design (regarding adequacy of available technology)	8.3.2.5.1
4.4.7	Design analyses, including those addressing impacts of surface conditions, rock characteristics, hydrology, and tectonic activity	8.3.2.5.7
4.4.9	Identification of technologies for construction, operation, closure, and decommissioning of the underground facility	8.3.2.5.9
4.5.2	Estimate the costs of the reference and alternative repository designs	8.2.2.3.2.4

A third requirement of Design Issue 1.11 is to limit the potential for excavation-induced changes in rock-mass permeability (Information Need 1.11.5, SCP Section 8.3.2.2.5). The Design Verification study will address this requirement by evaluating the extent of excavation-induced fracturing in selected locations of the ESF.

The Design Verification study addresses several requirements of Key Issue 2, which pertains to preclosure radiological safety. One requirement is to measure the rate of emanation of radon (^{222}Rn) from the repository host rock mass. ^{222}Rn is a decay product of uranium (^{238}U) which has been measured in quantities ranging from 1 to 5 ppm in the repository host rock horizon (Broxton et al., 1986). Contrary to its predecessors in the decay chain, ^{222}Rn is a gas, which emanates from exposed rock surfaces and through fractures. ^{222}Rn emits alpha particles and has a half life of 3.82 days. It decays to solid, short-lived daughter products (^{218}Po, ^{214}Pb, ^{214}Bi, and ^{214}Po; combined half-life of 49.55 minutes) that emit alpha, beta, and gamma radiation as they decay in turn. The daughter products are borne in the air and if inhaled may attach to the upper respiratory tract or lungs. The radiation particles emitted by these short-lived daughter products pose the most serious health hazard in the decay of radon (Rose, 1982a).

The rate of emanation of radon from a rock matrix is influenced by many factors, including mineral composition, temperature, air pressure, and the gas permeability, gas pressure, and moisture content of the matrix. The emanation rate from a rock mass is also influenced by the prevalence and characteristics of fractures.

Measuring the rate of radon emanation from the repository host rock and the mined tuff waste is called for in Design Issue 2.7, which is concerned with the features of the repository that relate to radiological safety including the impact of the site on the engineered systems and components. Although radon is not expected to pose a significant hazard in the repository, its contribution must be factored into assessments of overall radiologic exposure of workers (Performance Issue 2.2, SCP Section 8.3.5.4) and in assessing off-site releases of radiation (Performance Issue 2.1, SCP Section 8.3.5.3).

Radon daughter products could potentially pose a hazard to underground workers in two situations: during mining and when entering drifts after they have been sealed. Exposure of workers to radon is controlled with ventilation. Knowledge of the radon emanation rate of the rock mass is required to establish minimum allowable airflow rates at mining locations and to determine the amount of ventilation needed before a sealed drift can be entered.

Radon and radon daughters will be released to the atmosphere by way of the ESF ventilation exhaust and the tuff waste stored on the surface. The rate at which radon emanates from the rock forming the wall of the repository excavations and from the mined tuff waste must be known in order to estimate total releases of radiation from naturally occurring sources to the accessible environment as a result of repository construction.

Design Issue 2.7 also calls for measuring size distributions of airborne particles in the underground facilities. Airborne particulates (rock dust and diesel particulates) will affect the dispersal of radon daughters in the airstream, procedures for monitoring the airstream, and designs for air circulation and filtration.

The quantities and characteristics of particulates that can be expected to be generated during repository construction will be evaluated in the Design Verification study.

Performance Issue 2.4 (SCP Section 8.3.5.2) is concerned with retrievability of the nuclear waste. In order to satisfy regulatory requirements for retrievability, the underground openings must be able to survive in a usable condition, with reasonable maintenance, for approximately 100 yr. after construction begins (SCP Section 8.3.2.5). The Design Verification study will supply confidence to predictions of long-term usability of repository-sized drifts.

Within Key Issue 4, which is concerned with preclosure performance of the repository, the Design Verification study addresses resolution of Design Issues 4.2, 4.4, and 4.5. Design Issue 4.2 (SCP Section 8.3.2.4) concerns the nonradiological health and safety of workers. The Design Verification study addresses two design activities pertaining to this issue: verification of access and drift usability; and verification of adequate air quality and ventilation.

Design Issue 4.2 supports Design Issue 4.4 (SCP Section 8.3.2.5), which addresses whether the design, construction, and operation of the repository can be accomplished with reasonably available technology. The Design Verification study will demonstrate and document methods for excavation, support, and monitoring of repository-scale underground openings at the repository horizon. Also, data will be gathered for use in analyses to show that the design requirements for the repository ventilation system can be reasonably met.

Design Issue 4.5 (SCP Section 8.2.2.3.2) addresses costs. Results of the Design Verification Study will provide indirect input for estimating costs of excavation, support, and operation of the underground facility.

1.2.2 Regulatory Requirements

The specific regulatory requirements that are addressed by the Design Verification study are contained in 10 CFR 60, "Disposal of High-Level Radioactive Wastes in Geologic Repositories" (NRC, 1988). This regulation contains rules governing the authorization, construction, and operation of a geologic repository. Broader requirements are contained in 10 CFR Part 960, "General Guidelines for the Recommendation of Sites for Nuclear Waste Repositories" (DOE, 1988b).

The Design Verification study will address portions of the preclosure performance objectives listed in 10 CFR 60.111: protection against radiation exposures and releases of radioactive material, and retrievability of waste. Measurements of radon emanation from the host rock and evaluations of dust generated during construction will address the first objective, and all of the activities in the study will address the second. The aspect of retrievability addressed by this study is the ability to construct and maintain usable underground openings. While addressing the general topic of maintaining usable openings, the study also supports or addresses specific requirements to:

- provide a description of design considerations that are intended to facilitate permanent closure of the repository [10 CFR 60.21 (c)(11)];
- provide plans for maintenance and surveillance in the repository [10 CFR 60.21(c)(15)(v)]; and
- maintain records of construction of the underground facilities (10 CFR 60.72).

Other regulatory concerns that the Design Verification study addresses include:

- demonstrating that the underground facilities can be constructed using reasonably available technology and with reasonable costs [10 CFR 960.5-1(a)(3)];
- ascertaining whether complex engineering measures are required to circumvent difficult rock or groundwater conditions [10 CFR 60.122(c)(20)] or geomechanical properties [10 CFR 60.122(c)(21)];
- fulfilling design criteria for underground openings, including considerations for safety, retrievability of waste, and the potential for deleterious rock movement [10 CFR 60.131(b), 10 CFR 60.133(c), 10 CFR 60.133(e)]; and
- fulfilling criteria for excavation [10 CFR 60.133(f)].

One reason for long-term monitoring of openings in the ESF is to develop techniques for monitoring the performance of the emplacement drifts of the repository. This activity supports requirements for monitoring rock deformations and displacement in the repository [10 CFR 60.141(c)] and using methods to limit the time required to perform work in the vicinity of radioactive materials [10 CFR 60.131(a)(2)].

The measurements of radon daughter products in the ventilation air, that will be performed as part of this study, are required to satisfy the performance objective regarding radiation exposure and release of radioactive material. These measurements will contribute to requirements to develop a program for control and monitoring of radioactive effluents and occupational radiation exposures [10 CFR 60.21(c)(7)], and to develop a means to limit concentrations of radioactive material in the air [10 CFR 60.131(a)(1)].

Exposure to radon daughter products is also regulated by the Department of Labor, Mine Safety and Health Administration (MSHA) through 30 CFR Part 57 subpart D, which sets limits on air quality, radiation and physical agents in underground ventilation air. MSHA regulations also specify exposure limits on dust and gaseous agents introduced into ventilation air by the rock strata or mining equipment.

Revisions of existing standards is currently underway through proposed rules 30 CFR Parts 58 and 72, which will set exposure limits for diesel particulates, and 30 CFR Part 56 which will revise criteria for air quality, chemical substances and will set repository protections standards.

2.0 Rationale for the Design Verification Study

Following are discussions of the rationale for conducting each of the Design Verification experiments, the rationale for the physical layout of the experiments, and constraints on the experiments.

2.1 Rationale for In Situ Design Verification Experiments

The rationale for each Design Verification experiment is discussed below.

2.1.1 Evaluation of Mining Methods Experiment

It is anticipated that the mining methods used in the ESF will be adjusted to suit changes in ground conditions as techniques are refined through experience. The Evaluation of Mining Methods Experiment provides for documentation of these adjustments, the reasons for making them, and their results. This documentation will allow repository designers and constructors to make use of experience gained in ESF excavations. Further, detailed investigations will be conducted into the excavation of repository-scale openings in a variety of ground conditions with the goal of developing procedures appropriate for repository excavations.Correlation of this experience with rock mass quality will provide the basis for extrapolating the ESF experience to the repository excavations.

Although emphasis is placed on evaluating the techniques for excavating drifts, the scope of this experiment also includes main access excavation techniques that will be used to penetrate the overlying strata

Current plans call for excavation of the ESF drifts using mechanical mining methods (DOE, 1991). It is likely, however, that some of the repository will be excavated using drill and blast methods.

2.1.2 Evaluation of Ground Support Systems Experiment

This experiment will monitor the selection and the performance of ground support systems when they are used. The most appropriate ground support system for an underground opening depends on many factors, including the mechanical characteristics of the rock mass, the in situ stress field, external loads to which the rock and supports will be subjected, the geometry of the opening, environmental conditions, the lifetime of the opening, allowable closure and rockfall, and costs. Ground support systems will likely be selected using a methodology developed by Hardy and Bauer (1991) based upon a combination of empirical methods using rock mass classification for isothermal conditions and numerical modeling to account for the effects of heat and seismic loading of the rock.

Two empirical rock-mass classification schemes that are well-known and widely used are the South African Council for Scientific and Industrial Research Geomechanics Classification, or Rock Mass Rating (RMR) (Bieniawski, 1973), and the Norwegian Geotechnical Institute Tunnelling Quality (Q) Index (Barton et al., 1974). The drift design methodology proposed by Hardy and Bauer (1991) uses both of these classification systems. The Q Index is used as the basis of ground support selection because of its extensive case history data base. The RMR system has been more extensively correlated with rock mass mechanical properties (strength, deformation modulus) and is used to develop scaled properties that provide the basis of preliminary numerical analyses.

The impacts of heat and seismic loading of drifts are not considered by either system, and are therefore addressed through numerical modeling. Data developed in the ESF construction, correlating ground support and rock mass quality, will be used to verify application of the classification system and to incorporate site specific and application specific parameters to customize the empirical design to the tuff environment.

It is expected that the predominant ground support in the ESF and in the repository will be rock bolts with wire mesh [SCP, Section 8.4.2; Site Characterization Plan Conceptual Design Report (SCP-CDR) (SNL, 1987), Section 3.3.1.3]. This system is in widespread use at the Nevada Test Site, including in repository-scale openings in welded tuff (Zimmerman and Finley, 1987). The combination of rock bolts and wire mesh has the advantages of:

- being readily adaptable to local variations in ground conditions and changes in opening geometry,
- permitting viewing of the excavated surfaces, and
- being relatively economical.

However, the performance of this type of support in a fractured welded tuff under high heat loads has not yet been demonstrated.

A recommended ground-support selection system for the repository will be developed based on experience gained in the ESF and on analyses. These activities include:

- observing the ground support selection system used in the ESF;
- observing the performance of selected ground support systems over a range of ground conditions;
- demonstrating the performance of supports under high-heat conditions and thermally induced loads (e.g., Study 8.3.1.15.1.6, In Situ Thermomechanical Properties); and
- modeling the effects of geologic anomalies, heat loads, seismic loads, and time on ground supports.

The Evaluation of Ground Support Systems experiment will encompass the first two of these activities. For some combinations of joint spacing, joint orientation, and intact rock and joint properties, the unheated environment studied as a part of this experiment may provide the most severe test of drift stability. This may occur where heat loads increase normal stresses across joints near the excavation, resulting in an increase in shear strength. Hardy and Bauer (1991) describe this heat induced improvement in drift stability with respect to empirical design methods. Findings will be used to develop a site-specific rock mass classification scheme with corresponding recommendations for ground support systems.

The effects of thermal loading on ground support are addressed in study 8.3.1.15.1.6, In Situ Thermal Properties, where experiments designed to heat large sections of a repository scale drift are planned. Preliminary modeling studies on the effects of heat loads on ground support performance are presented by Hardy and Bauer (1991) and will provide a basis for incorporation of support performance verification into the In Situ Thermal Properties experiments. The extent of ground support performance measured in heated tests is limited because of plans to perform only two drift scale tests. The current philosophy in the SCP is to provide verification of the numerical modeling and empirical design approach with limited tests. Rock mass quality and modeling analyses will provide the basis for extrapolation to different ground conditions.

2.1.3 Monitoring Drift Stability Experiment

The repository openings must be designed so that they can remain usable for approximately 100 yr. after construction begins in order to satisfy the requirements of 10 CFR 60.111(b)(1). This requirement is interpreted to mean that the openings must be sufficiently stable that continued usability of the openings can be ensured with infrequent maintenance (e.g., repair of mechanical supports and removal of fallen or loosened rock). Additional requirements are imposed by MSHA regulations in 30 CFR Part 57, which covers acceptable support fixtures and support maintenance.

To be able to predict whether the repository openings will remain usable throughout the operational life of the repository, many factors must be considered. These include the intact rock characteristics, fracture characteristics, time-dependent relaxation of the rock mass, effects of the heat generated by the waste, effects of dynamic loading, longevity and maintenance requirements of the mechanical supports and the rock surfaces, and usage requirements. Predictions of usability of the repository drifts over their design life will be based on results of modeling and in situ demonstrations. In the ESF, experiments will be conducted to demonstrate the stability of repository-scale openings over a range of ground conditions, over an extended period of time, through any natural or induced seismic events that might occur during the experiment, and under heat loads simulating those expected to be generated by the emplaced waste. All of these demonstrations except the heat loading will be included in the Monitoring Drift Stability experiment. The heat loading is not included in the Monitoring Drift Stability experiment as it is only a monitoring activity. The effects of heat loading will be examined in the In Situ Thermomechanical Properties experiment of SCP 8.3.1.15.1.6.5.

Current plans emphasize measuring displacements rather than stresses for monitoring drift stability. According to Bieniawski and Maschek (1975), displacement measurement is the most useful monitoring technique for tunnels because displacements:

- can be measured directly (as opposed to stresses, which are derived from measured strains);
- can be monitored simply and continuously; and
- provide information on the overall movement of the rock mass, as opposed to

point measurements, which can vary tremendously within a rock mass.

The Monitoring Drift Stability experiment consists of widespread monitoring of drift-wall convergence, borehole measurements of rock mass relaxation in the main drifts, and recording of maintenance activities and rockfalls throughout the facility. Stress or stress-change measurements may be incorporated if a reliable means for monitoring them over the long term can be demonstrated.

Cross-drift convergence measurements will be the primary means of monitoring and evaluating drift stability in the ESF, and the same is likely to be true in the repository. Convergence measurements will also be used to evaluate the impact of mining methods and the effectiveness of the ground supports in the ESF.

Measurements of rock mass relaxation using borehole extensometers will be made in repository-scale openings to furnish detail regarding the nature of convergence of the openings, and to validate models of the long-term behavior of the rock mass around openings.

Records of rockfalls and maintenance will be kept to enhance predictions of opening stability and to help establish criteria for usability of the drifts. Limited instabilities requiring reasonable levels of maintenance are expected during the operating life of the repository.

Measurements of absolute stress with increasing depth from the tunnel wall may be conducted to evaluate the degree of elastic response of the rock mass for verification of modeling approaches. These measurements would be made using borehole overcoring techniques which have proven application in geotechnical investigations. Repeated measurements over time would be correlated with long term deformation measurements to assess the degree of time dependent rock mass relaxation.

Another aspect of this experiment is the development of methods for monitoring the stability of the repository. Ongoing observation of the openings is necessary to ensure their continued usability. Several aspects of the repository combine to make the requirements for monitoring its underground openings unique; namely, the linear footage of openings that need to be monitored, the duration of the monitoring effort, the high temperatures that will be encountered, and the limited accessibility of some drifts due to heat and radiation. According to the designs presented in the SCP-CDR, the repository could have approximately 50-100 mi of drifts, depending on the waste emplacement configuration selected. As mentioned previously, drift usability must be ensured for up to 100 yr. after construction begins. After waste emplacement, access to some drifts will be restricted because of radioactivity and, eventually, because of temperature. To meet these unique needs, it is desirable to develop a system for monitoring drifts that is long lasting, can function in a severe environment, can be operated remotely, requires minimal maintenance, and can be implemented efficiently on a large scale. Monitoring systems used in the drifts of the ESF will be selected with these considerations in mind.

Monitoring microseismic activity is one promising technique for monitoring long term stability of repository drifts and will be included in this study. Microseismic emissions have been used for prediction of rock bursts in deep mining projects and both equipment and techniques are well developed. Arrays of geophones would be installed outside the plane of the repository. Source locations of each microseismic event would be calculated from the variations in arrival time at each geophone and then plotted on maps of the tunnels. Areas of potential instability and excessive rock movement may correlate with the density of microseismic events over time. Variation of stress caused by heating of waste emplacement tunnels could provide a continuous energy change to drive the microseismic activity. Installation of a microseismic array for construction of the ESF would allow testing of the concept and correlation with rock mass quality maps. The mechanical mining activities could provide the stress change to drive the microseismicity at the tunnel face.

Crosshole, active seismic measurements will also be conducted at specific locations where associated drift stability and ground support instrumentation has been emplaced.

2.1.4 Air Quality and Ventilation Experiment

The primary function of the Air Quality and Ventilation experiment is to collect data that will be used to design the repository ventilation system and to validate the repository ventilation system models.

Quantities that will be evaluated for use in the models include the rate of emanation of radon gas from the tunnel walls and mined tuff waste, presence of other hazardous gases, airway friction factors, amounts and types of particulates generated by mining activities, and the coefficient of heat transfer between the rock and the ventilation air. The radon emanation measurements are also needed for radiation safety evaluations to determine whether special action will be needed to limit the exposure of underground workers to radon daughters and to calculate total radioactive releases to the atmosphere.

The ventilation parameters of pressure, airflow, temperature and humidity are required for analysis of the In Situ Thermomechanical Properties study (8.3.1.15.1.6). Heat balances and transfer of heat to ventilation air around tests are important to model validation, which will include comparisons of predictions with measured conditions in the ESF. The survey of airflows and pressures as well as heat balance surveys will be conducted for this purpose.

Measurements of the tunnel wall rock temperature change with time, in conjunction with the ventilation measurements can be used to evaluate convective and radiative heat transfer between the rock and air. This data will be used to verify ventilation cooling modeling for repository drifts.

2.2 Alternative Experiment Designs and Measurement Concepts

The actual components and configuration of the Design Verification experiments will be dictated by aspects of the ESF design that are not yet finalized, such as method(s) of excavation, materials used for ground supports, and the facility layout. To accommodate this uncertainty, experiment descriptions in this study plan are broad enough to encompass multiple credible design concepts. In many instances, details specific to the current ESF design concept are described. These details serve to illustrate the intended scope of the investigations and will be superseded if necessary once the ESF design is finalized.

The measurement concepts in the Design Verification study are generally straightforward. In most cases, standard techniques are available; they will be used unless superior alternatives are demonstrated in advance (through prototype testing, earlier ESF testing, or developments unrelated to the YMP). Currently identified alternative techniques that may be investigated are discussed in the experiment descriptions (Section 4.0).

The Evaluation of Mining Methods and Evaluation of Ground Support Systems experiments consist primarily of making records of excavation and construction activities and procedures. As an alternative to simply requiring specific information from the ESF A/E, the option of assigning responsibility for on-site data collection to other investigators was considered. This alternative was discarded in the interest of simplicity: unnecessary duplication of effort would be avoided (the A/E will require similar records for purposes of verification), and the number of personnel required to be present at an excavation site would be reduced. Further integration of the Design Verification study plan with the requirements of the A/E repository designers will be undertaken as the ESF planning proceeds. The majority of this study plan addresses specific technical areas of repository performance which require data development to support design. Specific data needs of the A/E designers need to be identified and the responsibility to produce the required data assigned.

To evaluate drift stability, the measurement of displacements will be emphasized. Changes in stress states could also be used to indicate changes in stability; however, stress changes are more difficult to measure and interpret than displacements, particularly in jointed rock. For example, borehole inclusion stressmeters were used to measure changes in stress resulting from excavation of welded tuff at G-Tunnel. The instruments were reportedly difficult to calibrate and install, and it was suspected that long-term results were affected by shifting of the instrument relative to the borehole (Zimmerman et al., 1988). Hoek and Brown (1980), citing the tendency to creep of the cementing agents bonding the gage to the borehole, also noted that stress changes are difficult to monitor over time.

The air quality and ventilation experiment entails the use of standard measurement techniques. Measurements of radon daughter concentrations in ventilation air will be based on techniques prescribed by 30 CFR 57 Subpart D. Literature associated with uranium mining describes experimental configurations for determining radon emanation rates from crushed rock samples, boreholes, and in isolated drifts. More complex experiments are required to characterize the influence of environmental conditions.

Prototype testing may be required to determine the feasibility of the measurements, the effects of physical configurations and environmental conditions, and the range of results that can be expected. It is expected that the final experiment configuration will consist of a combination of the above options.

2.3 Rationale for Arrangement of Experiments

This section presents the rationale for the location, number, timing, and duration of measurements in the Design Verification study experiments.

Most of the experiments in the Design Verification study will be conducted in the main drifts and accesses, where a range of ground conditions should be encountered at repository dimensions (DOE, 1991). A programmatic advantage to conducting the experiments in the main openings is that they will have minimal impact on other ESF activities since relatively few other activities are planned for these drifts [current plans call for geologic mapping (SCP Section 8.3.1.4.2.2.4), hydrologic testing at major faults (SCP Section 8.3.1.2.2.4), and collecting samples for laboratory testing]. In most cases, it will not be necessary to collect data in the main test area as well. Exceptions include monitoring rock mass behavior at intersections and certain short-duration ventilation tests described in Section 4.4. Also, if apparently anomalous ground conditions are encountered in the main test area, the ground supports and rock mass behavior in these areas may be monitored as well.

Locations for stability measurements will be selected to serve one of two purposes: either to document rock mass behavior in "representative" conditions, or to document "extreme" conditions. To obtain measurements in "representative" conditions, stations will be located throughout the main drifts at a maximum spacing of 200 ft. (60 m), avoiding any local anomalies. Measurements in "extreme" conditions will be obtained by locating stations around and across faults and other geologic anomalies, and at drift intersections. It is estimated that about 50 stations will be installed, although this total will be affected by the extent of variation in ground conditions. Plans for monitoring rock mass performance are discussed further in Section 4.3.

Other tests that will be carried out at various locations throughout the main drifts and accesses include ground support performance tests and one or more radon emanation tests. Although general locations for these tests are proposed in this Study Plan (Section 4), precise locations will depend on ground conditions: anomalous zones will be avoided except where the intent is to evaluate their effects (e.g., if extremely weak ground is encountered requiring steel sets for support, the supports must be evaluated under those conditions).

Timing of the experiments will depend on the ESF mining schedule. Monitoring of mining methods and support installation will coincide with excavation. Monitoring of drift stability and support behavior will begin as soon as the measurement areas are excavated and supported and will continue throughout the site characterization testing period. In at least some of the drifts, monitoring will continue after submittal of the license application (as a part of performance confirmation) to increase confidence that usable openings can be maintained for the duration of the operational life of the repository.

The radon emanation measurements are predicted to last from 3-6 months.

The remaining activities composing the Design Verification study are of short duration and flexible timing.

2.4 Constraints on the Study

Following is a discussion of the Design Verification study in terms of potential impacts on the site, simulation of repository conditions, required accuracy and precision of parameters to be measured, time constraints, statistical relevance of data, and interrelationships with other activities.

2.4.1 Potential Impacts on the Site

The potential impacts of construction of the ESF on the site are discussed in Section 8.4 of the SCP. Because the only additional excavation required specifically for this study consists of the drilling of short boreholes, this study is not expected to have any additional impacts on the site.

2.4.2 Simulation of Repository Conditions

The scale of repository openings will be simulated in the main drifts, and the geologic variability of the repository block will be investigated by the extent of the drifts. Techniques for mining, supporting, and monitoring used in the Design Verification experiments will simulate some of those expected to be used in the repository. Thermal loads that will be imparted by the waste will not be simulated in the Design Verification study experiments, but will be investigated in other studies.

2.4.3 Required Accuracy and Precision of Parameters to be Measured

Tentative performance goals and associated confidence levels for the performance of the underground openings are given in Section 8.3.2.4 of the SCP. Medium confidence levels are associated with all of these goals; this term is not defined in any quantifiable fashion. Quantities will be measured with the highest precision that is reasonably achievable. The accuracy and precision of each quantity to be measured are discussed separately in the experiment descriptions (Section 4).

According to Section 8.3.5.4 of the SCP, the radon emanation rate must be known with a high degree of confidence. No numerical performance goals are stated. Radon concentrations will be measured with the highest precision obtainable with both continuous monitoring instruments and discrete volume samplers.

2.4.4 Time Constraints

The scheduling and duration of the Design Verification study experiments are justified and discussed in Sections 2.2 and 6.0, respectively. Monitoring of construction activities will be constrained by the scheduling of the activities being monitored. Drift stability monitoring will not be constrained by the termination of site characterization, although a cutoff date will be imposed on data to be used in evaluations to support license application. The other experiments can be completed well within the schedule for site characterization testing. The radon emanation measurements are constrained by the need to begin testing reasonably soon after excavation of the surfaçes to be used for evaluations.

Slow down of excavation progress due to the installation of instrumentation for monitoring drift stability will be avoided. It is not expected that this study will significantly affect the construction schedule for the main accesses or the main test area.

2.4.5 Statistical Relevance of Data

The convergence measurements and rockfall estimates in the Monitoring Drift Stability experiment will be used to establish performance criteria for the repository and will be evaluated against tentative performance goals, which are stated numerically in Section 8.3.2.4 of the SCP. The degree of confidence associated with the goals (described in SCP Section 8.1) has been given qualitatively as medium. Given the lack of in situ data regarding the variability of the rock to be encountered, the variety of cross-sections in which measurements will be made, the tentative nature of the goals, and the qualitative nature of the requirements, it is not possible to design the Design Verification study experiments on a statistical basis.

The data that will be collected in this study will be representative of the conditions encountered throughout the ESF. However, because of the uncertainty in geologic variation, the level of confidence of any statistical conclusions that will be drawn from the data cannot be predicted. The ground conditions affecting the aspects of design to be investigated (e.g., conditions affecting excavation and ground support) have been judged to be representative of those that would be encountered throughout the repository host block (Nimick et al., 1988), based on available geologic and borehole data.

2.4.6 Interrelationships with Other Activities

The Design Verification study experiments are interrelated with construction activities and ESF operations, other studies, and one another.

Interrelationships with Construction Activities: The Evaluation of Mining Methods experiment has a strong relationship with mining activities. The investigator, A/E, and constructors must cooperate to refine mining methods, share data collection tasks, and to collect data in a form that can be used by the investigator. However, the responsibility for the results of the study lie with the investigator who must take all steps necessary to insure success of the experiments, including data collection.

Data gathering for the Air Quality and Ventilation experiment has a strong interrelationship with data gathering for the ESF health/safety systems and with the common data-gathering effort of the ESF Integrated Data System. This interrelationship is discussed in more detail in Section 4.4. Needless duplication of data gathering will be avoided.

The A/E will need the information gathered by this study plan in support of the Title III effort. Consequently, and to avoid duplication, this study plan will be integrated with the A/E requirements.

Interrelationships with Other Studies: The Design Verification study is strongly related to the Excavation Investigations study (SCP Section 8.3.1.15.1.5; DOE, 1989a), which consists of the Access Convergence experiment, the Demonstration Breakout Room experiment, and the Sequential Drift Mining experiment. The Access Convergence experiment will complement access mining evaluations in the Evaluation of Mining Methods experiment. The Demonstration Breakout Room experiment involves monitoring and evaluating mining methods, ground supports, and stability of repository-scale rooms in the high lithophysal zone; information gathered in the room will be incorporated in the Design Verification study evaluations. Also, if the Demonstration Breakout Room experiment precedes excavation of the main drifts, experience gained from this earlier experiment will benefit later experiments in the main drifts. The Sequential Drift Mining experiment is a detailed evaluation of the effects of excavation on the surrounding rock. Results of this experiment will enhance the basis for interpreting the measurements made in the main drifts. The complementary activities in the Design Verification study and the Excavation Investigations study will not impose constraints on one another, except for a need for exchange of technology and data.

The Design Verification study will also interrelate with the In Situ Thermomechanical Properties study (SCP Section 8.3.1.15.1.6). The Design Verification study experiments will be conducted at ambient temperatures. To predict opening stability under heated conditions and to develop a complete methodology for design of the repository drifts, the performance of openings in a heated rock mass must be incorporated. This will be accomplished in the Heated Room experiment (SCP Section 8.3.1.15.1.6.5). Ventilation system cooling demonstrations and moisture transfer investigations will also be addressed in the design of the Heated Room experiment. Radon daughter concentrations will be measured in the Canister Scale Heater experiment (SCP Section 8.3.1.15.1.6.2) and possibly in the Heated Room experiment; these results will be compared with ambient-temperature measurements collected in the Design Verification study.

Another relationship exists between the Design Verification study and the geologic mapping activity (SCP Section 8.3.1.4.2.2.4). The photographs and maps created during excavation will be used in the Design Verification study to evaluate excavation results, to classify the rock masses, and to document the shape and condition of the openings. The photogrammetric records obtained during mapping may also be used for comparisons to detect changes over time such as block movement; the feasibility of this has not yet been investigated.

Characterization of the hydrologic properties of faults (SCP Section 8.3.1.2.2.4) may interrelate with the Design Verification study activities where fault zones are exposed in the ESF drifts. Data on excavation, ground support used, and long-term stability will be of interest because the fault zones represent anomalous conditions. If the historic motion of water through the fault has deposited uranium in the zone, any groundwater moving along the fault will contain higher radon content which would be liberated by the breakup of water droplets as they impact the excavation floor. Integration of the activities of the two studies will be performed to prevent interference.

Lastly, the Design Verification study has an interrelationship with the Laboratory Thermal Properties and Laboratory Thermal Expansion Testing studies (SCP Sections 8.3.1.15.1.1 and 8.3.1.15.1.2, respectively). Some of the core drilled for extensometer holes will be used for laboratory testing to examine the spatial variability of porosity and thermal expansion.

Interrelationships Between Design Verification Experiments: The Design Verification study experiments are strongly interrelated. The records of rock mass quality kept as part of the Evaluation of Ground Support Systems experiment will be used to evaluate the influence of ground conditions on drift stability and excavation results (in the Monitoring Drift Stability experiment and the Evaluation of Mining Methods experiment, respectively). Ground support performance monitored in the Evaluation of Ground Support Systems experiment will be considered in evaluations of drift stability. Conversely, rock convergence measurements (Monitoring Drift Stability experiment) will be used to evaluate performance of ground support systems and mining methods.

2.4.7 Test-to-Test Interference

Section 8.4.3 of the SCP is a discussion of the potential for interference between tests in the ESF. Because the nature of the Design Verification experiments is primarily observational, no special constraints are required to incorporate these activities in the ESF testing, and no additional perturbation to natural conditions (stress, temperature, moisture, etc.) will result from these activities.

3.0 Quality Assurance Requirements and Documentation

All work will be performed in accordance with the Sandia National Laboratories Quality Assurance Program Description. The experiments will be governed by SNL Quality Assurance Grading Report (QAGR) S1242114A and QAGR S1242114B, which specify applicable QA criteria, and associated Quality Assurance Control Specification Records, which specify implementing documents and procedures. The tasks addressed in QAGR S1242114A are for site characterization activities; the tasks addressed in QAGR S1242114B are related to scoping studies.

For each experiment, an Experiment Procedure (EP) describing the operational and technical procedures required to fulfill the experiment objectives will be produced. EPs and Technical Procedures (TP) currently identified as applicable for the Design Verification study experiments are listed in Table 3.0-1. Other procedures may be required as planning of the experiments progresses.

Monitoring activities will be performed in the ESF starter tunnel. For these activities, experiment logbooks will be maintained to provide a continuity of documentation before, during and after the performance of the monitoring activities. In addition to providing design verification data, these activities will provide experience that will be used to develop the EPs for the remainder of the activities in the Design Verification study.

For each experiment, three types of reports will be produced: experiment descriptions, data reports, and interpretive reports. For the Evaluation of Mining Methods, Evaluation of Ground Support Systems, and Monitoring Drift Stability experiments, it is anticipated that "as-built" descriptions of the locations and conduct of the experiments will be necessary to supplement the descriptions given in the EPs, because of geologic and procedural uncertainties. For the Air Quality and Ventilation experiment, the experiment description will be embodied in the EP. Final reports on the radon emanation measurements will be produced separately from those on the rest of the Air Quality and Ventilation activities because of the diversity of uses for the radon data.

The schedule for these reports in relation to the experiments is discussed in Section 6.

Table 3.0-1. Experiment Procedures and Technical Procedures Required for the In Situ Design Verification Study

Evaluation of Mining Methods Experiment

EP	Evaluation of Mining Methods Experiment Procedure

Evaluation of Ground Support Systems Experiment

EP	Evaluation of Ground Support Systems Experiment Procedure
TP-072	Procedure for Determination of Rock Quality Designation
TP-184	Procedure for the Instrumentation of Rock Bolts for Strain
TP-185	Procedure for the Measurement of Loads on Steel Sets
TP-186	Procedure for Pull-Testing Rock Bolts
TP-187	Procedure for Strength-Testing Shotcrete

Monitoring Drift Stability Experiment

EP	Monitoring Drift Stability Experiment Procedure
TP-006	Procedure for Installation and Operation of Multiple-Point Borehole Extensometers
TP-014	Procedure for Inspection of Boreholes
TP-193	Procedure for Installation and Operation of Tape Extensometers

Air Quality and Ventilation Experiment

EP	Air Quality and Ventilation Experiment Procedure
TP-028	Procedure for Installation and Operation of Instrumentation for Monitoring Radon Emanations
TP-170	Procedure for Monitoring Dust Generated During Construction and Operation
TP-172	Procedure for Monitoring Ventilation Air Velocity and Quantity
TP-188	Procedure for Conducting Radon Measurements Using the Lucas Flask Method
TP-189	Procedure for Operation of Instant Working Level Meter and other Radon Daughter Measuring Devices
TP-190	Procedure for Measuring Barometric Pressure
TP-192	Procedure for Measuring Air Temperatures and Relative Humidity
TP-191	Procedure for Measuring Differential Air Pressure
TP-192	Procedure for Measuring Air Temperatures and Relative Humidity
TP-194	Procedure for Determining Heat-Transfer Coefficient

4.0 Description of In Situ Design Verification Experiments

Descriptions of the four experiments composing the Design Verification study are presented in this section. Experiment designs are preliminary and will be revised based on the results of pretest analyses and experience gained in prototype testing and prior ESF testing.

4.1 Evaluation of Mining Methods Experiment

The Evaluation of Mining Methods experiment consists of documenting the excavation of the ESF and performing investigations to optimize the excavation of repository-scale openings in the repository host rock. This experiment will be conducted primarily in the main drifts; in addition, excavation of the main accesses will be documented to investigate construction techniques and to incorporate data pertinent to the strata overlying the repository horizon. The experiment will not be conducted in conjunction with mining in the main test area to avoid interference with activities in this area. Excavation information obtained in the main drifts and main accesses, along with that collected in the demonstration breakout room and sequential drift mining experiment (DOE, 1989a), will be adequate for the purposes of this experiment. Results will be used to provide data for use in repository design and to make recommendations for mining in the repository.

Alternatives for excavation methods in the ESF include both full- and partial-face mechanical mining (tunnel boring machines and roadheaders), and conventional drill and blast excavation. Although current planning emphasizes the use of mechanical mining, it is generally the case in civil underground construction projects that some drill and blast excavation is required. General plans for this experiment therefore include tasks that allow the evaluation of the two different approaches with respect to repository performance. Specific work plans will be adjusted on the basis of final construction planning for the ESF.

4.1.1 Description of Procedures

The mining evaluations consist of data collection activities that provide a basis for evaluating the impacts of the different mining methods on repository performance. For the purposes of this study, the performance areas potentially impacted include:

- overall performance of the mining methods,
- interaction of the ground conditions with the excavation technique,
- extent and character of the disturbed zone around the excavation,
- utilization of water during mining,
- character of the mined tuff waste with regard to its surface storage and future use for backfilling the repository, and
- inventory of materials introduced into the ESF during construction.

The activities in this experiment primarily consist of documenting the mining process and developing the data base to both assess the impacts and to correlate the impacts with the specific operational practice. Activities that would be documented are:

- documenting location, rock mass quality, mining method used, equipment

deployed, details of equipment configuration and performance;
- documenting and assessing the results and effects of excavation; and
- evaluating and comparing the performance impacts.

These three activities are discussed in the following sections.

4.1.1.1 Documenting Methods and Equipment

Different types of information will be collected for the two types of mining (mechanical mining and drill and blast)

For the mechanically mined excavation, machine operating parameters will be collected by the constructor. These would include penetration rate, cutter thrust, cutter bit configuration, and utilization parameters. Utilization parameters include cutting time, mechanical downtime, service downtime, and ground support downtime. These data will be correlated with location and rock mass quality to provide the basis for using the results to assess impacts on repository performance. Analysis of the time data on machine performance will provide the basis for evaluating repository schedules and cost.

Drill and blast mining involves a different set of parameters to be collected. In addition to the data on excavation rate and rock mass quality, the equipment utilization and cycling between different operation tasks will be monitored. Drill and blast mining requires monitoring of the different unit operations in the excavation process which are:

- drilling the blast round,
- explosive loading and blasting,
- blast fume ventilation,
- scaling and ground support installation, and
- mucking the broken tuff waste rock.

The operations of primary interest with respect to repository performance impacts are the blast round design and scaling and ground support installation. The latter is evaluated in the ground support system experiment of this study.

Details on the blasting operation are of interest because of their influence on the disturbed zone around the excavation. Minimization of the disturbed zone requires careful design of the pattern of holes, charges of explosives and sequence of initiation of the explosives. Blast design would be performed by the constructor with monitoring in this experiment to include:

- round design, design basis, and calculations;
- actual hole patterns, explosive charging, and initiator layout; and
- peak particle velocity.

Blast damage to the rock fabric has been shown to be a function of peak particle velocities associated with the blast (Holmberg and Persson, 1980). Peak particle velocities and charge densities in the perimeter blast holes would be used as the physical basis for correlating blast damage with blast round design.

Use of water in the mining process needs to be documented, because of concerns to minimize the amount of water introduced into the repository host rock during construction. These records will be kept to compare the performance of the different mining methods.

A great deal of the operational type information required in this experiment is expected to be collected by the constructor of the A/E. Coordination of the data gathering activities will be required. Periodic checks of the required record keeping will be necessary to assure that accurate records of the data are being maintained.

For these evaluations, highly accurate measurements are less important than consistently thorough records of procedures and observations.

4.1.1.2 Documenting and Assessing Mining Results

Results of the monitoring studies must be correlated with monitoring of the impacts on repository performance. The primary impacts of the mining methods that are to be examined are:

- condition of the excavation,
- characterization of the disturbed zone around the excavation,
- water use,
- inventory of materials introduced into the repository associated with mining methods, and
- size gradations of the mined tuff waste.

Specific monitoring activities associated with the performance impacts are outlined in this section.

The condition of the resulting excavation will be recorded and correlated with the local rock mass quality. Specific data recorded will include geometry of the opening, interaction with structural features, overbreak and underbreak, visible half-hole castes in blasted rounds and scaling requirements.

The disturbed zone around the excavations will be characterized by several activities. Damage comparison between machine mined and conventionally mined sections of the drifts can be conducted by comparing fracture frequencies in core data and surface mapping. Boreholes drilled for instrument installation will be examined using downhole video cameras with damage assessed by fracture frequency logging. Another technique to estimate depth of blast induced damage is comparison of absolute stress measurements using borehole overcoring in radial boreholes. Results of stress measurements in roadheader mined versus drill and blast drifts were employed by Agapito et. al. (1984) to estimate the impact of excavation technique on the strength of oil shale pillars. Stress profiles in the walls of machine mined drifts showed relatively high stresses near the excavation boundary and smooth transitions to the in situ stress field with increasing distance from the excavation.

Crosshole seismic tomography might be useful for damage investigation. Tomography can be used to interpret propagation velocity profiles around the excavation. Comparison between mechanically mined and drill and blast mined drifts could be used to develop damage depth correlations.

Water use during mining has been identified as a potential impact on repository performance and will be monitored. Impact of waster usage will be compared by measuring changes in saturation between the floor, walls, and roof of the excavation. Moisture content of the mined tuff waste will be monitored to determine the amount of water used in the mining process that is transported out of the ESF. These data, along with moisture transported in ventilation air, will be used to develop the introduced water balance for repository design.

A materials inventory will be developed to identify types and quantities of materials introduced into the ESF by the mining process. This inventory will be used in geochemical assessments that are required to identify which materials must be removed before repository closure. The inventory will include items such as:

- diesel exhaust particulates on drift walls;
- spilled fuel, lubricates or other fluids from mining equipment;
- rock bolts, cement grouts, concrete, resins, shotcrete, mesh or other materials used for ground support; and
- explosives.

Size gradations of the mined tuff waste will be measured and correlated with mining method and rock mass quality. Mined tuff waste will be used to backfill the repository and will be required to meet specifications for limitation of fine materials. Changes in cutter type and spacing on the mechanical mining machines may impact fines productions. Further degradation may result during handling. These data will support the evaluation of available backfill quality and design for materials handling systems required to prepare the tuff waste for backfilling of the repository.

4.1.1.3 Conducting Mining Evaluations

The ESF openings will provide an opportunity to demonstrate the feasibility of excavation of repository-scale drifts in a range of ground conditions within the repository host block. All aspects of the excavation process will be recorded as described in Section 4.1.1.1.

4.1.2 Quantities and Locations of Measurements

Records of mining procedures will be kept by the constructor for all ESF excavations. The constructor will be directed to measure and record the operational information called for in Sections 4.1.1.1 and 4.1.1.2. Assessments of the extent of mining-induced fracturing or disturbed zone, rock mass quality, moisture content and size gradation will be the responsibility of the principle investigator of this experiment. This experiment places no additional testing requirements on excavations in the main test area; measuring and recording requirements beyond those that will be executed by the constructor (e.g., photographs) will be undertaken only in the main drifts and accesses.

4.1.3 Range of Expected Results

Average rate of advance for ESF mining and the expected depth of fracturing for mechanical mining is not yet known. Parameters monitored in this experiment are expected to vary as a function of mining method and rock mass quality. In general, conditions expected in the ESF are within the experience in other underground construction projects.

4.1.4 Accuracy and Precision of Measurements

A great deal of the information collected will be qualitative descriptions. Many of the quantitative parameters require relatively low precision (advance, time duration) and will be derived from constructor logs. For quantitative records such as drillhole locations, depths, and angles, the use of a tape measure and protractor is standard practice and will provide adequate precision for this study. Alternatively, dimensions can be taken from photographs.

In the SCP, overbreak and depth of mining-induced fracturing are given as tentative goals to satisfy the performance measure of safe access to underground facilities (Section 8.3.2.4). A repository goal is to limit the average overbreak to 0.5 ft. (0.15 m) with medium confidence; this implies that measurements should be accurate to within +/- 0.25 ft. (0.076 m). The repository goal is to limit the extent of blast-induced fracturing to less than 3 m on the average, with medium confidence. Depths of the intersections of individual fractures in boreholes will be measured to the nearest 0.05 m and are expected to be accurate to within +/- 0.025 m. The determination of the depth of the disturbed zone will be based on comparative measurements and its accuracy is not currently known.

The levels of accuracy and precision of measurements that will be required for this experiment may be refined based on findings of the Excavation Investigations study and other previous or concurrent activities.

4.1.5 Required Instruments, Equipment, and Materials

Requirements for instrumentation and equipment for the Evaluation of Mining Methods experiment include the following standard equipment:

- photographic equipment,
- borehole televiewer,
- borehole undercoring equipment,
- neutron probe, and
- cross hole seismic equipment.

4.1.6 Representativeness of Results

The Evaluation of Mining Methods experiment incorporates observations in the main drifts and accesses of the ESF and the results are expected to represent the geologic variation in the repository.

4.1.7 Performance Goals and Confidence Levels

The information gained from the Evaluation of Mining Methods experiment will support predictions of drift stability, a performance measure stated in Sections 8.3.2.4 and 8.3.2.5 of the SCP. This performance measure lists tentative goals for allowable overbreak, depth of excavation induced fracturing, quantities of rockfall, and maintenance frequencies. It is important to emphasize that the goals stated in the SCP are guides for development of testing programs, not targets that must be met (SCP, Section 8.1).

The goals for overbreak and excavation induced fracturing were discussed in Section 4.1.4. The best way to ascertain whether goals for rockfalls and maintenance frequency can be met is to monitor the performance of the underground openings. This activity is described in the Monitoring Drift Stability experiment, Section 4.3.

Appropriate types and quantities of mining equipment must be selected for repository operations in order to achieve the 3,000 ton/day mining capacity goal in the SCP, Section 8.3.2.5. Evaluations of the equipment used in the ESF will contribute to development of performance predictions and specifications for mining equipment to be used in the repository.

4.2 Evaluation of Ground Support Systems Experiment

The Evaluation of Ground Support Systems experiment will contribute to the design of ground support systems for the repository by evaluating the performance of various support systems for openings in the repository host rock and by evaluating the methodology used to select supports in the ESF. Correlation of rock mass quality with ground support performance will result in improvement of the design process. Monitoring support loads for isothermal rock behavior will provide a basis for numerical assessments of thermal loading of the supports. Because heated rock tests will be limited, the ground support experiments provide the only basis to include geologic variability into the design process.

The ground support selection methodologies that will be used in the ESF and in the repository will likely resemble the conceptual methodology described in the SCP-CDR, Section 3.3.1.3.3 and by Hardy and Bauer (1991). These systems contain categories of ground support that correspond to credible ranges of ground conditions based on using an empirical classification scheme. The support categories range from rock bolts on variable spacing to steel sets with rock bolts, shotcrete, and wire mesh. It is expected that most excavations will be supported using rock bolts and wire mesh (as discussed in Section 2.1.2).

4.2.1 Description of Procedures

The Evaluation of Ground Support Systems experiment can be divided into two parts: an evaluation of support performance and an evaluation of the support selection process.

4.2.1.1 Evaluation of Ground Support Performance

Evaluation of ground support performance consists of observing and assessing the installation and performance of the supports used in the ESF and measuring the load-displacement relationships and ultimate capacities of ground supports. The geometry of the excavation will vary depending on whether it is machine mined or drill and blast mined. However, the general character of the support systems will be similar and will accommodate the same measurements.

The following items will be monitored during support installation: materials used, support configurations, installation techniques, timing of installation after excavation, time required for installation, distance of supports from the face, manpower requirements, and equipment used. Difficulties and deficiencies will be documented.

The supports will be evaluated in terms of effectiveness and efficiency. Effectiveness will be evaluated primarily in terms of drift closure, rockfalls, and block movement, which are to be measured and recorded as part of the Monitoring Drift Stability experiment (Section 4.3). Also, records will be kept of visual observations such as evidence of support loading or unloading, and maintenance and reinforcement needed.

In situ loads on selected rock bolts may be measured by using bolts that provide information on the load being exerted. Results of field tests of bolts instrumented using vibrating wire strain gages (Maleki et. al., 1985) indicate suitable instrumentation is available. Other techniques with potential application include measurements using ultrasonics, or possibly using fiber optic cables as strain gauges. A final selection will depend on the types of bolts used and on prior development and testing. Rock bolt pull tests will be conducted to assess the load-bearing capacity of the support system (including the bolt, the anchor, and the surrounding rock).

Where shotcrete is used, cores will be taken periodically for strength testing and for inspection of the bond of the shotcrete with the rock. Regular visual inspections will be conducted to look for cracking and spalling. Other options for evaluating shotcrete performance and loading that have been considered are strain measurements on incorporated wire mesh and embedment of hydraulic pressure cells. The use of conventional strain gauges on wire mesh has the disadvantage of limiting measurements to isolated points. Hydraulic pressure cells were used in the G-Tunnel Welded Tuff Mining Evaluation experiment (Zimmerman et al., 1988) and will be installed in the concrete shaft liner, if a concrete shaft liner exists in the final design of the ESF. It is doubtful that the shotcrete applied to the drift walls would be thick enough to incorporate such an instrument. Because of these drawbacks, neither option is currently being considered for use in this experiment.

If steel sets are used, loading will be measured using calibrated load cells. These instruments have an advantage over strain gauges because they give an average measurement, as opposed to measurements at isolated points. Calibrated load cells can accurately measure loads in steel sets if properly aligned with forces to be measured. Eccentricity of loading caused by moments or shearing forces in the vicinity of the load cell can result in incorrect readings. Strain gages will therefore be used in addition to the load cells to provide a second measurement system.

The efficiency of a support system will be evaluated in terms of cost of materials, time and equipment needed for preparation and installation, safety concerns, flexibility of the system to accommodate variations in ground conditions and opening dimensions, and maintenance requirements. Ground support interaction analyses (e.g., Hoek and Brown, 1980) will be used to demonstrate the effectiveness and efficiency of the support systems.

Long term corrosion of support systems in not expected to be observable in the ESF because the environment is dry and the rock minerals are not corrosive. Evidence of corrosion will be qualitatively monitored during the ESF operation. Electrochemical problems with structural materials (steel sets, bolts, shotcrete, etc.) are unanticipated but will also be checked periodically as part of this experiment.

4.2.1.2 Evaluation of the Ground Support Selection Process

During excavation of the drifts, the decision-making process used to select a ground support system will be evaluated and iteratively refined. This process will likely consist of (1) exercising criteria to decide where and when to perform rock mass classifications, (2) evaluating rock mass characteristics, (3) assigning values to the characteristics and combining the values in a prescribed manner, (4) assigning a classification to the rock mass according to its "score," and (5) designating the support system associated with the classification.

The support selection methodology that will be prescribed for the ESF by the A/E will serve as a starting point. As excavation of the drifts proceeds, the system will be tailored to fit the site conditions by modifying criteria for determining when to reevaluate the classification, incorporating new parameters, adjusting parameter weights, and adjusting the classification boundaries.

Support design is based upon support capabilities versus estimates of support loading for the various rock qualities. Quantitative assessment of support loads for the repository environments can lead to optimized design at the required safety factors.

4.2.2 Quantities and Locations of Measurements

Evaluations of ground support installation and performance will be confined to the main drifts with three exceptions: any supports that are installed in the main test area but not in the main drifts will be investigated; all maintenance and reinforcement of supports, regardless of location, will be noted; and separate evaluations will be conducted in the demonstration breakout room and sequential drift mining area as part of other experiments (DOE, 1989a). Areas without ground support will be monitored to provide comparative data on support performance. Evaluations of the ground support selection process will be confined entirely to the main drifts.

Rock bolt load measurements will be conducted in each different class of rock in which they are used. For planning purposes, it is estimated that for each class, twelve rock bolts will be monitored.

Evaluations of other types of ground supports will be undertaken wherever they are used. For each area where shotcrete is applied, a minimum of three cores will be taken, allowing for redundancy of measurements. If the investigator determines that more are needed (e.g., because of inconsistencies in the shotcrete mix, application methods, or ground conditions) additional cores may be taken. In each area where steel sets are used, two will be instrumented with load cells. This number was selected as the minimum possible, allowing for redundancy, to keep testing as economical as possible and still provide adequate results.

4.2.3 Range of Expected Results

The ranges of expected results are presented only to serve as a planning guide. The rock bolt load capacities are expected to fall in the range of 100-300 kN, based on laboratory testing of fully-grouted rock bolts by Pells (1974). The compressive strength of shotcrete will be in the range of 30-40 MPa (Hoek and Brown, 1980). The maximum load on steel sets is on the order of 900 kN, an estimate based on a procedure described by Proctor and White (1977).

4.2.4 Accuracy and Precision

Accuracy of measurements of support capacities, loads, and strains should be in accordance with published recommendations when applicable and commensurate with the state of the art.

4.2.5 Required Instruments, Equipment, and Materials

Instrumentation required for this experiment includes strain- or load-monitoring instruments for rock bolts and load cells for steel sets. Equipment needs include rock bolt pull-testing equipment and compressive strength testing apparatus for shotcrete cores.

4.2.6 Representativeness of Results

Ground supports will be monitored throughout the drifts, where a variety of ground conditions are expected to be encountered. As discussed previously (Section 2.1.2), this experiment will not be conducted under conditions fully representative of the repository because the waste-generated heat will not be simulated.

4.2.7 Performance Goals and Confidence Levels

No specific performance goals are addressed by the Evaluation of Ground Support Systems experiment. The information gained from this experiment will address the usability of underground openings and associated allowances for closure, rockfall, and maintenance frequencies, which are performance measures listed in Sections 8.3.2.4 and 8.3.2.5 of the SCP. These quantities will be measured in the ESF as part of the Monitoring Drift Stability experiment, the subject of the next section of this study plan.

4.3 Monitoring Drift Stability Experiment

The primary objective of the Monitoring Drift Stability experiment is to demonstrate the ability to design, construct, and maintain repository- scale openings in the host rock that can be expected to remain usable for the 100-yr. operational life of the repository. This objective will be accomplished by:

- monitoring cross-drift convergence throughout the main test level,
- monitoring rock mass relaxation around the repository-scale openings,
- observing and recording rockfalls and maintenance activities throughout the ESF,
- installing microseismic monitoring equipment capable to generate maps of microseismic activity.

Convergence measurements will be used to evaluate short- and long-term stability of the drifts. Also, these measurements will be used to judge the effects of different mining methods, supports, and opening geometries. Present plans are to use manually operated tape extensometers to measure cross-drift convergence. Pins will be placed to measure displacement horizontally approximately at midsection and vertically as close as practical to the center. Measurements will also be made on diagonals (roof to ribs and floor to ribs). The pins will be installed as close as practical to the advancing face.

A significant proportion of the convergence of an opening will occur before the first measurement can be taken, unless instrumentation can be installed immediately at the face. For example, for a circular opening in a hydrostatic stress field, the radial elastic displacement at a distance of about 0.1 times the opening diameter behind the face is approximately 50% of the total that would be experienced under plane strain conditions (Brady and Brown, 1985). Costin and Bauer (1988) reported similar findings from finite-element analyses of convergence of the first exploratory shaft. In situ investigations of the initial displacements associated with mining advance will be conducted in the Sequential Drift Mining experiment (DOE, 1989a). In cases where the initial closure can only be estimated, it is preferable to judge the stability of the opening on the basis of relative comparisons rather than absolute changes; i.e., changes in displacement over time and comparisons of measured displacements with those in other sections (e.g., Cording, 1974).

Even though high priority is given to face advance rate in drift excavation, opportunities for instrument installation at the face generally exist. These opportunities occur due to cycle time, maintenance time and equipment downtime. Recent studies of TBM utilization on sic different projects by Nelson et. al. (1985) indicated that the average utilization of the TBM was only 40%, and that approximately one third of all working shifts had some downtime for regular maintenance. Wyman (1985) reports that the Intrenchment Creek project was organized around daily maintenance such that two eight hour shifts were dedicated to advancing the tunnel, with the third eight hour shift dedicated to TBM maintenance. Close coordination with the constructor will be required so that instrument installation can be accommodated with delaying advance rates.

The depths of rock movement will be evaluated in the main drifts using borehole extensometers. A typical multi- point borehole extensometer (MPBX) instrument station showing the arrangement of the instruments and the locations of cross-drift convergence measurements is shown in Figure 4.3-1. MPBXs and convergence pins will also be installed at drift intersections (Figure 4.3-2). In all cases, precise locations will depend on the ground conditions encountered, and where allowed given the presence of utility lines.

Additional extensometers will be installed where major faults or shear zones are encountered. For a fault with a narrow shear zone, MPBXs will be installed on either side, in the same configuration as that shown in Figure 4.3-1. Depending on the dip of the fault, its angle of incidence with the drift, and the nature of the fault gouge, it might be possible to install an MPBX through the shear zone so that movements can be recorded across it. For wider fault zones, installation of MPBXs within the fault gouge might not be feasible because of the nature of the gouge, and the use of sliding micrometers will be considered. Convergence measurement pins will be closely spaced through and around major fault zones.

Optimum spacing of the MPBX anchors will be determined after the instruments have been selected and their capabilities have been assessed. Because movements will be greatest near the opening, most of the anchors will be placed closer than one opening diameter from the surface. The boreholes will be examined by televiewer to ensure that the anchors will be situated in competent rock. Ideally, the deepest anchor is in rock unaffected by the excavation. According to linear elastic theory, the stresses induced by a circular opening in a hydrostatic stress field are within 5% of the free-field stresses at a distance of 5 radii from its center (Brady and Brown, 1985). However, finite-element analyses of a repository-scale drift in the host rock have predicted that displacements at this depth can still be significant--up to 30% of that predicted at the surface (Costin and Bauer, 1988). The actual movement of the deepest anchors of two opposing MPBXs can be determined by comparing the total cross-drift convergence measured between the MPBX heads to the sum of the displacements measured by the MPBXs. Final selections of anchor depths and other instrument configuration details will be based on results of further analyses, testing in G-Tunnel, instrument limitations, and earlier geomechanical experiments in the ESF.

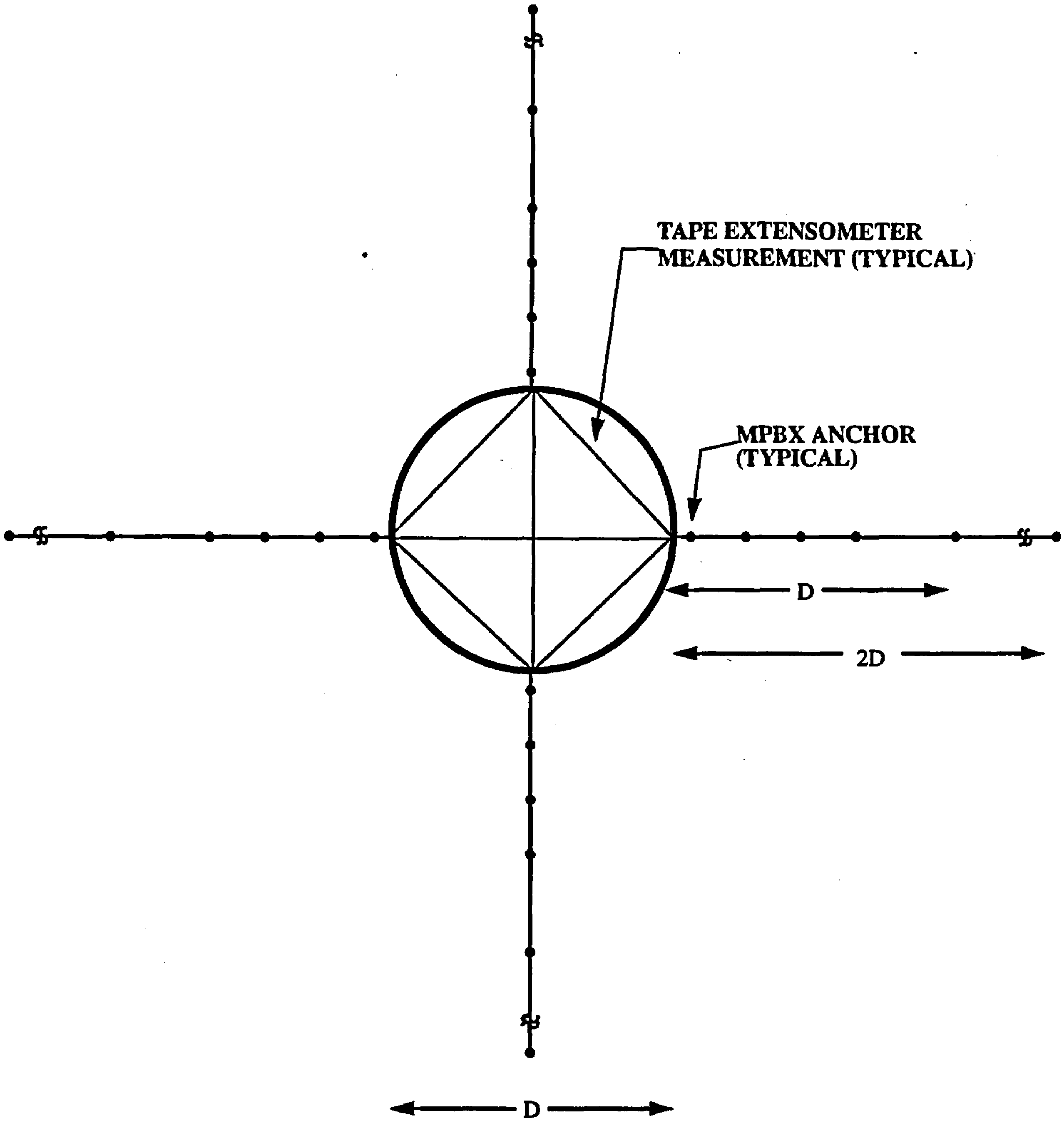

Figure 4.3-1. Typical Configuration of Multi-Point Borehole Extensometer (MPBX) Instrument Station

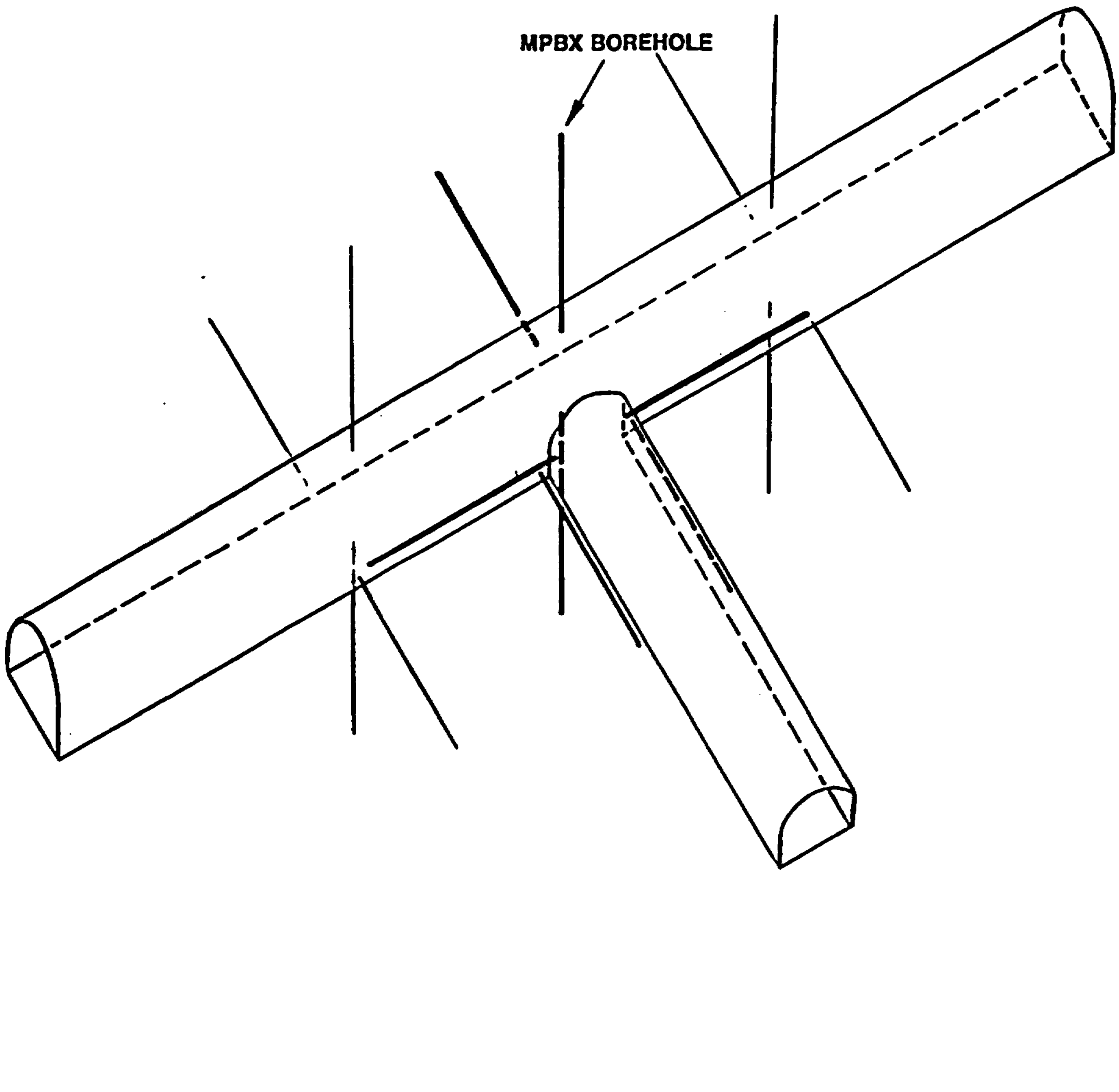

Figure 4.3-2. Proposed Configuration of Multi-Point Borehole Extensometers at Drift Intersections.

The Monitoring Drift Stability experiment will also include routine visual inspections for rockfalls, opening of fractures and discrete block movement. Records of maintenance activities including rock scaling and removal, and adjustment and reinforcement of supports will also be kept.

A second objective of the Monitoring Drift Stability experiment is to demonstrate the ability to monitor the performance of repository-scale drifts to identify potential instabilities before safety is compromised or repair requirements become excessive. This will be accomplished by regularly evaluating magnitudes, changes, and spatial variations in closure and by performing routine inspections to look for changes in the rock mass and distress to supports. This information will also be used to develop criteria for assessing stability of the repository openings.

A third objective of the Monitoring Drift Stability experiment is to develop techniques for monitoring stability in the repository. The alternative methods for monitoring drift usability that are currently being explored include ultrasonics, fiber optics, lasers, and photogrammetry. One or more of these will be tested in the drifts of the ESF if preliminary studies and field tests show promise.

4.3.1 Quantities and Locations of Measurements

Cross-drift convergence will be measured in the drifts of the main test level, in the TSw2 unit in the main access; at drift intersections; around geologic anomalies; in the Calico Hills unit; and at intervals no greater than 200 ft. (60 m). This maximum spacing has no statistical basis; it is judged to be the greatest distance that should be allowed between measurements in reasonably similar rock.

MPBXs will be installed in groups of four (Figure 4.3-1) in the middle of each main drift and at drift intersections (Figure 4.3-2).

4.3.2 Range of Expected Results

Based on excavations in welded tuff in G-Tunnel (Zimmerman et al., 1988), cross-drift convergence measurements are expected to be less than 20 mm in the first year after excavation. (This excludes the significant portion of total convergence that will occur before the measurement points are installed.) After the first year, convergences are expected to be considerably less. Rock mass relaxation measurements are expected to be less than 10 mm in the year after excavation, and to be considerably less in following years.

4.3.3 Accuracy and Precision

Drift closure should be measured with sufficient accuracy to confirm that closure rates are less than 1 mm/yr. (according to the tentative goal set in SCP Section 8.3.2.4).This goal will apply only after the initial excavation induced convergence (presently unspecified) has occurred. This tentative performance goal implies that measurements should have a resolution of at least 0.1 mm. In the G-Tunnel Welded Tuff Mining Experiment, the tape extensometer used was calibrated to be accurate to within plus or minus 0.13 mm, which is similar to manufacturers' specifications.

The convergence measurement pins will be installed close to the advancing face. Pins will be installed in a variety of ground conditions; therefore, a variety of installation techniques may be required. These pins should be installed with the intent of continued use for many years.

Rock mass relaxation should also be measurable with sufficient accuracy to address the performance goal of closure rates below 1 mm/yr. A discussion of the accuracies of MPBXs in general, and several brands in particular, is provided in the Excavation Investigations Study Plan (DOE, 1989a). Because the instruments will be used for several years, functional life, maintainability of the instrument, and stability of the anchors are important considerations.

Tentative goals given in SCP Sections 8.3.2.4 and 8.3.5.2 suggest limits to allowable average annual rockfall of 3 tons/1,000 ft. (30 kN/300 m), and a maximum single-block weight of 2 tons (20 kN). A medium confidence level is needed. This is interpreted to mean that visual estimates of block sizes and records of numbers and sizes of truck loads of fallen rock removed will be sufficiently accurate.

4.3.4 Required Instruments, Equipment, and Materials

Instrumentation required for the Monitoring Drift Stability experiment, as currently configured, consists of MPBXs and tape extensometers with associated measurement pins.

4.3.5 Representativeness of Results

The results of the Monitoring Drift Stability experiment are expected to be representative of the geologic variability that will be encountered in the repository horizon because data will be gathered throughout the drifts on the main test level. The convergence measurements will be a function of many factors, including ground conditions, mining methods, supports installed, and opening geometry. Because all of these factors will vary throughout the main drifts, the representativeness of results to repository conditions must be assessed carefully. Rock mass relaxation measurements will be confined to the main drifts, where the planned geometry of the repository drifts is duplicated. The main drifts will remain at ambient temperatures throughout the test period, so the thermal environment that is expected in the repository will not be simulated.

4.3.6 Performance Goals and Confidence Levels

The information gained from the Monitoring Drift Stability experiment will substantiate the tentative goals listed in SCP Sections 8.3.2.4, 8.3.2.5, and 8.3.5.2 supporting performance measures that address long-term accessibility to underground facilities of the repository. The tentative goals listed are closure rate less than 1 mm/yr. in main accesses and drifts and less than 3 mm/yr. in emplacement drifts; total closure less than 6 in. (15 mm) in 100 yr.; average annual rockfall less than 3 tons/1,000 ft. (30 kN/300 m) and less than 2 tons (20 kN) /individual block; and maintenance frequency greater than 5 yr. for minor maintenance and greater than 25 yr. for major maintenance. The approach to addressing these goals was discussed in Section 4.3.3.

4.4 Air Quality and Ventilation Experiment

Ventilation design is based upon total air quantities required to dilute the air pollutants produced throughout the excavations to acceptable levels for safe operations. After air quantities are established, the network of tunnels and systems to direct the ventilation air must be devised, and the energy required to transport the air through the network must be derived. Based upon the total quantity of air flowing and the required energy, the equipment necessary can be specified.

The primary objective of the Air Quality and Ventilation experiment is to measure parameters needed to design the repository ventilation systems. The experiment consists of the following activities:

- radon daughter measurements to define radon emanation rates;
- measurements and characterization of other gases as needed;
- surveys to determine airflow velocity, pressure loss, temperature, and moisture content;
- friction factor determinations;
- Particulate quantity and identity measurements; and
- thermal exchange coefficient measurements.

The rates of emanation of radon gas from the rock mass and from mined tuff waste will be measured using the same technique. The sample (rock surface or volume of tuff waste) is confined in dead air for a period of greater than 15 days to allow the radon daughter concentration to come to equilibrium. Radon gas emanates from the sample at a steady rate and undergoes decay to a series of radioactive daughter products and finally to a non-radioactive daughter. The level of radioactivity gradually increases to a constant value, where the decay process is in equilibrium with the radon emanation. The emanation rate is related to the level of radioactivity in the air when equilibrium is reached.

Variation of radon emanation rate will be measured throughout the repository in boreholes radiating from drift walls. These measurements will test the full range of rock conditions exposed in the ESF. Several larger scale measurements will be performed in dead-end drifts where the drift can be sealed for the required time. Confirming, dynamic measurements would then be made by ventilating the drifts and measuring steady-state radon daughter levels at various air flow rates.

Other measurements of radon daughter levels will be made to correlate the levels to air pressure and dust concentration. These effects are expected to be small, and would be derived from monitoring conducted over the life of the ESF. Some of the measurements may be made by the constructor as part of compliance with health/ safety requirements (30 CFR 57.5038,)

Monitoring for other gases in the ESF is the responsibility of the A/E. According to Project requirements and federal, state, and local regulations, the facility must be monitored for the presence and concentrations of oxygen, carbon monoxide, carbon dioxide, methane, nitrous oxides, sulfur dioxide and radon (DOE, 1989b). Collection of these data will not be duplicated for the purposes of this experiment. However, if unexpected concentrations of particular gases are discovered, the scope of this experiment may be expanded to include further studies.

Additional data that the A/E is required to gather and that might be useful for the purposes of this experiment are measurements of air temperature, humidity, speed and volume of flow and direction (DOE, 1989b). These parameters may also be measured at the main accesses and elsewhere by the integrated data system (LANL, 1988).

Surveys of airflows and pressures and temperatures and humidities will be conducted around the ESF. Each survey will be conducted over several days using portable instruments. Friction factors for the drifts surveyed will be calculated from these measurements.

Particulate sampling will be required in several different phases of the ESF construction process. Dust production at the face, associated with operation of mechanical mining systems, must be sampled. Both cascade impactors and filter samples will be taken and correlated with ventilation air volume, face advance rate, cutter configuration, and dust suppression technique. These samples will determine average concentration in the ventilation air. The particulate samples themselves must be analyzed to show size gradation and mineral constituents. Allowable particulate concentrations are based upon concentration of the respirable fraction and on the silica content. Other samples will be collected throughout the ESF facility in ventilation mains and at specific tuff wasted handling and transfer points

Correlations between radon daughter concentrations and particulate contents will also be developed by parallel measurements

Additional particulate sampling will be required, under new MSHA regulations, to separate diesel particulate concentration from total particulates. Techniques for this type of sampling are currently under development.

Investigations will be conducted to determine the thermal exchange coefficient between the rock and the ventilation air, in conjunction with the In Situ Thermomechanical Properties experiments (SCP section 8.3.1.15.1.6). Heat balance surveys in the ventilation air and cool-down of the test drifts by ventilation air, as indicated by the test instrumentation, will provide the necessary data.

4.4.1 Quantities and Locations of Measurements

The radon emanation measurements (both the borehole measurements and the larger scale dead-end drift testing) will be located at the end section of a drift or in an alcove on the Main Test Level.

Surveys of average airflow and air pressure and temperature and humidity (heat balance) will be conducted throughout the ESF, once a month for twelve consecutive months.

Friction factor measurements will be made in several locations as dictated by the variety of ground conditions and support systems. Measurements to determine the correlation between friction factors in a drift with and without ducting cannot be made in the main drifts because through-flow conditions are required. A location for these measurements in the main test area has not been selected.

Air samples for dust assessment will be taken at working faces, muck-handling sites, drilling sites, roadways and other dust sources.The quantity of samples needed has not yet been determined.

4.4.2 Range of Expected Results

Expected ranges of results are shown in Table 4.4.2-1. Ranges are based on climatic data at the site, experiences in similar underground spaces, and limits set by the various applicable regulations, codes, and standards. Emanation rates of radon from welded tuff are not known. The approximation used in the SCP is 0.48 pCi/(m-s), which is a value measured on sands derived from tuff. Predictions of types and quantities of other gases to be encountered are not given. Dust concentrations will be extremely variable, so those predictions are also not given. The ranges of results, as well as the accuracy and precision with which they will be measured, will be determined or refined through prototype testing.

Table 4.4.2-1 Ranges of Expected Results for Measurements to be Taken During the Air Quality and Ventilation Experiment

Parameter to be Measured	Estimated Range
Radon emanation rate	unknown
Air velocity	50-4000 ft./min (0.3-20 m/s)
Barometric pressure	12-15psi (85-100kPa)
Fan pressure	0.5-14 in. water gauge (120-3,500 Pa at 15°C)
Pressure differential	.001-4.000 in water gauge (0.25-1,000 Pa at 15°C)
Air temperature	0-110° F (-18 to 43°C)
Humidity	0-100%

4.4.3 Accuracy and Precision

All of the activities in this experiment involve techniques that are commonplace in the mining industry. Instruments well suited for these applications are commercially available. Recommended resolutions for the instruments currently planned for use in the Air Quality and Ventilation experiment are included with the instrument list in Table 4.4.3-1. Results of the monitoring will be compared to exposure criteria cited in MSHA regulations (30 CFR Parts 56,57, 58 and 72).

No requirements for accuracy of measurements of the radon emanation rate are given in the performance goals. However, the radon emanation rate from the rock at the repository horizon must be determined with a high level of confidence (SCP Sections 8.3.5.3, 8.3.5.4, and 8.3.2.3). The concentration of radon gas will be measured to the greatest accuracy practical with continuous monitoring equipment.

4.4.4 Required Instruments, Equipment, and Materials

A list of instruments, equipment, and materials needed for the Air Quality and Ventilation experiment is presented in Table 4.4.3-1. The levels of precision and resolution are tentative. Some of the instruments will be needed only for a short time and could be provided by the contractor performing the work.

4.4.5 Representativeness of Results

Most of the measurements made as part of this experiment will be representative of the repository to the degree that the ground conditions in the ESF represent the ground conditions throughout the repository block.

Current plans are to conduct radon emanation measurements at a single site. It is expected that spot measurements throughout the ESF will indicate whether this is sufficient. Because radon concentration in the air is affected by ventilation rates, barometric pressure, temperature, humidity, surface coating, and airborne dust load, it will range widely even when the emanation rate is constant. However, if spot measurements are found to vary significantly under similar ventilation and environmental conditions or if measurements are unexpectedly high (0.3 working levels), radon emanation measurements might be repeated at other locations.

4.4.6 Performance Goals and Confidence Levels

The radon emanation rate from the repository host rock mass is a design parameter listed in SCP Sections 8.3.5.3 and 8.3.5.4; the associated performance goal is to have further measurements determine the actual value. The emanation rate needs to be determined with a high level of confidence.

The other ventilation parameters do not directly fulfill performance goals; rather, they will be used in design analyses.

Table 4.4.3-1. Summary of Instrumentation, Equipment, and Materials Required for the Air Quality and Ventilation Experiment

Item	Precision or Resolution (if known)
Radon Measurements	
Continuous monitoring system:	
Radon monitor, modified Lucas flask	1 pCi/l
Working level monitor 1	0.01 working level
Velocity transducer	
Barometric pressure transducer	
Temperature/relative humidity transducers	
Lucas flask for radon concentration measurement	0.1 pCi/l
Instant working level	
Materials for bulkhead	0.01 working level
Pressure Measurements	
Pitot static tubes	
Low differential pressure gauges	2-4% full scale
Vinyl tubing	
Flexible tubing	
Meteorograph for continuous monitoring of	
pressure	0.015 psia
temperature	0.5°C
humidity	3%
Survey barometer	0.0015 psia
Altimeter	
Air Velocity Measurements	
Vane anemometers	
Air velocity/temperature meter	1%
Extension rod	
Smoke tube	
Stop watch	0.1 sec
Measuring tape	
Temperature Measurements	
Sling psychrometer	
Digital psychrometer	0.1°C
Aspirated hygrometer	1%
Infrared thermometer	1°C
Heat stress monitor	0.1°C
Dust Sampling	
Various samplers, with pumps and filter assemblies	
Geometric Measurements	
Measuring tape	

5.0 Application of Results

Results of the Design Verification study will be used to select methods for excavation and support of underground openings in the repository, to design the repository ventilation systems and in repository cost and schedule estimations. Results will also be used indirectly to help predict the long-term behavior of repository openings.

As discussed in Section 1.2, findings will help satisfy performance assessment and design needs by (1) helping to demonstrate that the underground facility design will contribute to containment and isolation of the waste; (2) helping to demonstrate that the underground facility can be constructed, supported, and operated using reasonably available technology; and (3) contributing to radiologic safety predictions.

5.1 Evaluation of Mining Methods Experiment

Results of this experiment will contribute to demonstrating the constructability of repository-scale drifts in the repository host rock. The results will be used to develop recommended procedures for excavating the repository. Recommendations will be based on evaluations of the methods, materials, and equipment used in the ESF in terms of damage to the surrounding rock, water usage, and efficiency and will include techniques, materials, and equipment appropriate for excavating in the various ground conditions expected to be encountered in the repository. The evaluations will also provide information from which safety recommendations and predictions of advance rates for cost and scheduling assessments can be developed.

5.2 Evaluation of Ground Support Systems Experiment

Evaluations of the ground supports and selection system demonstrated in the ESF will be used to develop recommendations for supports and support selection in the repository. Results will also be used to develop safety recommendations and cost and scheduling predictions for the repository. Measurements of ground support loads and capacities will be used to assess the supports used, to conduct ground support interaction analyses and to develop criteria to evaluate drift stability in the repository.

5.3 Monitoring Drift Stability Experiment

The measurements made in the Monitoring Drift Stability experiment, along with stability measurements made in other experiments and performance data collected in the Evaluation of Ground Support Systems experiment, will contribute to predictions of the long-term usability of the repository drifts. Data will be utilized in preclosure performance assessment analyses and design analyses as described in the Drift Design Methodology (Hardy and Bauer, 1991).

The convergence measurements from this experiment will be analyzed for absolute magnitudes, rates of change, and spatial variability. This information will be used:

- to demonstrate the ongoing stability of repository-scale openings in the repository host rock and to demonstrate whether time-dependent deformation of the repository host rock is significant;

- to assess the effectiveness of different ground supports and mining methods and to evaluate the effects of ground conditions on stability;
- for routine monitoring of ESF drifts to identify areas of potential instability;
- to develop convergence-monitoring procedures for future use in the repository; and
- to develop site-specific criteria for assessing stability of the repository drifts.

Results of borehole extensometer measurements will be used to evaluate the depth of rock mass relaxation around repository-scale openings in various ground conditions and its changes over time.

Records of rockfalls and maintenance will be used to assess long-term usability, to evaluate the ground support system performance, and to develop criteria for assessing opening usability.

5.4 Air Quality and Ventilation Experiment

Results of this experiment will be used to design the repository ventilation systems. Radon emanation measurements will also be used in radiologic safety assessments and predictions.

6.0 Durations and Interrelationships of Experiments

The timing of the Design Verification study experiments is discussed in Sections 2.2 and 2.3.4.

Data collection for the Evaluation of Mining Methods experiment will coincide with the period during which the ESF is being mined.

The Monitoring Drift Stability experiment will begin with initiation of cross-drift convergence measurements in the TSw2 thermomechanical unit in the first ramp to be mined and will continue beyond site characterization and into the performance confirmation phase. A cutoff date will be established for data that will be used to support the license application. Installation of borehole extensometers openings will be scheduled so as to avoid delaying construction activities.

The Evaluation of Ground Support Systems experiment will start upon commencement of excavation and will terminate before the end of the site characterization phase. However, some support-load monitoring will continue as a stability monitoring function.

The schedule for the Air Quality and Ventilation experiment is flexible, with the exception of the radon emanation measurements, which should begin soon after the test area is excavated. This activity is predicted to last for 6 months; this estimate will be reassessed after prototype testing has been completed. The schedule for the other activities in the Air Quality and Ventilation experiment is flexible. These activities are of short duration and are not expected to interfere significantly with ESF operations or other experiments.

The experiment descriptions will be produced shortly after the ESF is constructed. Data reports will be produced shortly after data gathering is complete. Interpretive reports will be released in time for findings to be incorporated into the license application.

The exact schedule for the experiments is dependent upon the construction schedule for the ESF and the level of funding.

For each experiment in the Design Verification study, a milestone will be associated with the start of data collection and with each published report. These milestones are listed in Table 6.0-1.

Table 6.0-1. Milestones

Milestone Number	Description	Deliverable
Z975	Begin Data Collection for Evaluation of Mining Methods Experiment	Letter
Z977	Begin Data Collection for Monitoring Drift Stability Experiment	Letter
Z976	Begin Data Collection for Evaluation of Ground Support Systems Experiment	Letter
Z978	Begin Data Collection for Air Quality and Ventilation Experiment	Letter
T562	Experiment Description for Evaluation of Mining Methods Experiment	SAND Report
Z806	Data Report on Evaluation of Mining Methods Experiment	SAND Report
T561	Experiment Description for Monitoring Drift Stability Experiment	SAND Report
T560	Experiment Description for Evaluation of Ground Support Systems Experiment	SAND Report
T550	Data Report on Radon Measurements in the Air Quality and Ventilation Experiment	SAND Report
Z808	Data Report on Air Quality and Ventilation Experiment	SAND Report
T549	Interpretive Report on Radon Measurements in the Air Quality and Ventilation Experiment	SAND Report
Z927	Interpretive Report on Evaluation of Mining Methods Experiment	SAND Report
Z807	Data Report on Evaluation of Ground-Support Systems	SAND Report
Z948	Data Report on Monitoring Drift Stability Experiment	SAND Report
Z979	Interpretive Report on Air Quality and Ventilation Experiment	SAND Report
Z928	Interpretive Report on Evaluation of Ground-Support Systems Experiment	SAND Report
Z929	Interim Interpretive Report on Monitoring Drift Stability	SAND Report

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APPENDIX A

RIB/SEPDB DECLARATION

This report contains no data from, or for inclusion in, the RIB and/or SEPDB.