Excavation Investigations Study Plan

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EXCAVATION INVESTIGATIONS STUDY PLAN

1.0 Introduction

This Study Plan describes one series of in situ experiments that are intended to provide some of the data required for assessing the validity of the rock-mass constitutive models that will be used in the repository design process and to support the license application. Data from other studies, both laboratory and in situ, will complement the Excavation Investigations data set. This combined data base is expected to provide the information required to develop and evaluate the rock-mass constitutive models that will be used to provide estimates of the rock-mass deformational behavior resulting from repository construction and waste emplacement activities.

The approach that has been adopted to understand and predict the mechanical response of the rock mass to the conditions imposed by repository excavation and waste emplacement is to employ progressively more complex models (e.g., Morland, 1974; Thomas, 1980, 1982; Chen, 1986, 1987; Blanford et al., 1987), that contain an improved understanding of rock mass deformational processes, during continued analyses for repository design, performance and safety. These models attempt to incorporate those features that are likely to exert a significant influence on the types of overall deformational behavior so that important phenomena are identified and eventually defined in a manner that permits reasonable bounds to be placed on their magnitude. As these models are exercised and as experimental data are obtained, additional insight into the mechanics of rock mass deformational processes is gained. Careful variation of the geometric considerations that may influence the model (e.g., boundary conditions, fracture spacing, etc.) and the constitutive properties of the model can also help to identify the mechanics of the overall system and arrive at an understanding of the critical factors to include in a numerical model of a fractured rock mass.

1.1 Objectives of the Excavation Investigations Study

The experiments discussed in the Excavation Investigations Study compose one element in the approach that has been adopted to develop and validate the models required to confirm the repository design. The primary objective of these experiments is to obtain an adequate data base that can be used to continue to develop and eventually validate the rock-mass constitutive models used to predict deformational behavior (i.e., displacements and stress distribution). These experiments emphasize drill and blast underground construction techniques which should result in larger displacements, higher induced stresses and a thicker damaged zone, hence less stability than other mechanical mining techniques planned for parts of the underground facility. These models will be combined with a thermal model to predict the thermomechanical response of the underground openings to repository excavation and waste emplacement and to help develop an adequate design for stabilizing the underground facility.

Three experiments, Shaft Convergence, Demonstration Breakout Rooms, and Sequential Drift Mining, are designed to provide a data set that will be used to assess and eventually validate the rock-mass constitutive models developed for predicting the mechanical behavior of repository-size openings (Table 1.1-1). Each of these experiments is designed to facilitate the analyses that will be performed in the validation effort. All three experiments will be conducted in, or adjacent to, Exploratory Shaft 1 (ES-1) or at the Main Test Level within the underground facility. The potential impacts of construction activities related to the sinking of Exploratory Shaft 2 on the experimental results obtained in this Study are expected to be negligible as discussed in the SCP (Section 8.4) and by Gertz (1987).

The Shaft Convergence Experiment will provide data to compare with the predicted response of the rock mass and shaft liner during and after excavation. Limits on the range of shaft

Table 1.1-1: Summary Of Activities Associated With Each Experiment Discussed In The Excavation Investigations Study Plan (Site Characterization Plan Section 8.3.1.15.1.5)

Experiment	Activity
Shaft Convergence	In Situ Horizontal Stress Measurements Estimate of Stress Altered Region Liner Contact Pressure Measurements
Demonstration Breakout Rooms	Drift Convergence Measurements Estimate of the Stress Altered Region Excavation Efficiency Estimate
Sequential Drift Mining	Drift Convergence Measurements Rib Stress Change Measurements Estimate of the Stress Altered Region Excavation Efficiency Estimate Air/Water Permeability Measurements Ultrasonic Measurements

convergence rates and magnitudes and on the horizontal stress state will be established at a minimum of three stations located at different depths with varying geological and geomechanical characteristics. An evaluation of the shaft design criteria will be performed to ensure that liner stresses do not exceed design specifications.

Information gathered during the Demonstration Breakout Rooms Experiment will establish whether repository-size drifts can be constructed in welded tuffs at two locations having significantly different geomechanical characteristics, lithophysae contents, and fracture densities (Price, 1983; Scott et al., 1983) using available technology. The approximate location of the Demonstration Breakout Rooms will be determined using borehole data available prior to the start of shaft construction. The exact orientation will coincide with the orientation defined for the underground facility (MacDougall et al., 1987) with some possible minor variations based on observed geological and geomechanical characteristics. These experiments will assess the effect of certain local geologic variations (i.e., fracture characteristics and lithophysae content) on the design of the repository-size openings and will complete a preliminary evaluation of support requirements and excavation efficiency in different rock mass conditions. Results will be used to continue the assessment of constitutive models that will be further evaluated with results from the Sequential Drift Mining Experiment. Samples will be collected for laboratory tests described in other Study Plans to determine the characteristics of the intact rock and fractures. The Demonstration Breakout Rooms will also provide an underground location for conducting experiments discussed in other Study Plans that are intended to evaluate the in situ state of stress, modulus of deformation, mechanical strength, and thermal response of welded tuffs with varying geologic and geomechanical characteristics.

The Sequential Drift Mining Experiment is designed to enhance the data base required for validating the rock-mass constitutive models that will be used to predict deformations and stresses around the underground openings and assess the stability of the underground facility in support of the license application. The excavation of a repository-size drift will be closely monitored to determine displacement magnitudes and rates in the stress altered region which will be compared with predictions based on analyses performed using the rock-mass constitutive models. The results will also be used for evaluating the preliminary design concepts related to ground support requirements and excavation efficiency.

Other measurements and observations that will complement the data base developed with this Study Plan and be used in the model validation process emphasize those factors which influence the large-scale mechanical behavior of the rock mass (Table 1.1-2). These measurements and observations will be used to describe the geologic and geomechanical characteristics of the shaft and drifts in the Exploratory Shaft Facility, characterize the mechanical properties of the rock mass, intact rock and fractures, calculate the in situ state of stress, and provide a data base for validating the thermal model used to predict the rock mass thermal response. The information obtained in all of these Study Plans will collectively provide the basis for the predictive capability that is necessary to design stable underground openings which require minimal maintenance during the repository operational period.

1.1.1 Use of Excavation Investigations Study Results

The principal information requirements for resolving preclosure issues related to repository design center on the question of adequate support for the underground openings. The design and support of these openings are dependent on the rock mass characteristics, the in situ stress state and the geometry of the openings. The Excavation Investigations Study experiments will be performed within specific intervals of the Topopah Spring Member that contain the range in rock characteristics that are expected to be representative of the character-

Table 1.1-2: Study Plans That Will Provide Data To Support Model Validation Efforts And Improve The Understanding Of Deformational Processes Associated With Fractured Rock.

Study Plan	Description
8.3.1.4.2.1	Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area
8.3.1.4.2.2	Characterization of the Structural Features Within the Site Area
8.3.1.15.1.3	Laboratory Determination of Mechanical Properties of Intact Rock
8.3.1.15.1.4	Laboratory Determination of the Mechanical Properties of Fractures
8.3.1.15.1.6	In Situ Thermomechanical Properties
8.3.1.15.1.7	Rock Mass Mechanical Properties
8.3.1.15.1.8	In Situ Design Verification
8.3.1.15.2.1	Characterization of the Site Ambient Stress Conditions

istics encountered throughout the repository block (Nimick et al., 1988). The predominant fracture orientation within the Topopah Spring Member is vertical and fracture density is greatest within the densely welded portion of the Topopah Spring Member (Spengler et al., 1984). Experiments are planned that will be located in a portion of the Topopah Spring Member with lithophysae content that is expected to range up to 24 %, the maximum that should be encountered within the repository horizon (Nimick et al., 1988).

The vertical component of the in situ stress is expected to be governed by the lithostatic load calculated at any specific depth interval. Horizontal components of the stress state are controlled largely by the lithostatic load, tectonic effects and elastic properties of the rock mass. The magnitude and orientation of the three principal stress components will be evaluated during the in situ testing program. Variations in the state of stress associated with the underground openings can result from the geometry of the openings, heating of the rock by the emplaced waste or test equipment, and occasional man-induced or natural seismic events. The stress altered region associated with underground openings consists of both the blast damaged zone and stress redistribution zone which may overlap depending on several variables including rock mass characteristics and blasting techniques (Figure 1.1.1-1). The radial extent of the blast damaged zone can extend from several tenths of meters to in excess of one meter from the perimeter of the opening depending on local rock characteristics and the mining method employed (Holmberg and Persson, 1980). The stress redistribution zone may contain rock that has been strained both elastically and inelastically and whose distribution will vary depending on the shape, orientation and distribution of the openings and variations in the rock mass strength and deformability. Induced stresses in this zone are generally considered negligible beyond three opening diameters from the perimeter (St. John, 1987). The undisturbed in situ stress

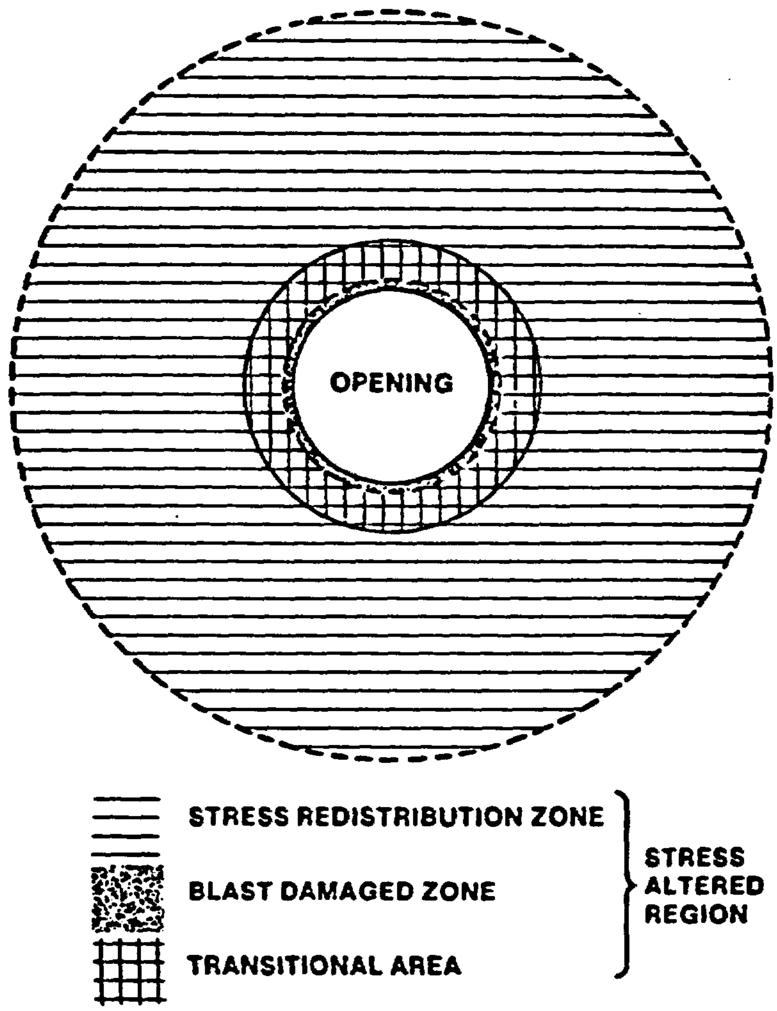

Figure 1.1.1-1: Schematic Illustrating The Stress Altered Region Comprised Of The Blast Damaged Zone And Stress Redistribution Zone. The Radial Extent Of These Zones Will Vary (Transitional Area) And May Overlap Depending On Several Variables Including Rock Mass Characteristics And Blasting Techniques.

state must be known or estimated prior to estimating the stress distribution within the stress altered region.

The cumulative effects of the static stress redistribution and the blast-induced dynamic stress changes that result in rock breakage must be accounted for in the design of the underground support system. If variations in the induced stress exceed the rock mass strength, localized failure may result. Failure of this type is a safety hazard that could possibly cause delays and increase costs in repository operations. Therefore, artificial reinforcement of the rock mass using rock bolts and wire mesh should extend beyond the blast damaged zone and well into the stress redistribution zone to provide an adequate support system.

1.2 Rationale and Justification For Information to be Obtained

1.2.1 Resolution of Performance and Design Issues

Performance Allocation was used by the NNWSI Project to establish appropriate issue resolution strategies for design and performance objectives in the NNWSI Project Issues Hierarchy. A general discussion of the performance allocation approach is provided in Section 8.1 of the Site Characterization Plan (SCP) and issue resolution strategies for each Site Program is provided in SCP Section 8.3.1.

Section 6.4 and 8.3 of the SCP provides a detailed discussion on the approach that will be used in the design of the underground openings. This approach emphasizes the need to ensure that openings associated with the underground facility will remain usable throughout the retrieval period (SCP Sections 6.4.8/10). The ability to predict displacement magnitudes and to estimate the limit and nature of the stress altered region is fundamental to our ability to ensure the retrieval of waste for up to 50 years after emplacement begins and to demonstrate that an underground facility can be constructed in welded tuffs using reasonable available technology. The assessment of stability that will be utilized initially involves meeting applicable health and safety standards using empirical design guidelines which are then checked by mechanical, thermal, and thermomechanical analyses to assess their adequacy. The ground control strategy concept (Hoek and Brown, 1980) establishes some limiting value on the amount of displacement and induced stress that cannot be exceeded during construction for the proposed design of the underground opening. This design approach then uses Tunnel Index methods (Barton et al., 1974; Bieniawski, 1976) to establish the initial ground support system requirements. These methods are then supplemented with a monitoring system to assess the effectiveness of the support system selected and, with boundary element and finite element calculations, to predict changes in stress and displacement due to thermal effects.

Information Need 4.2.1 (SCP Section 8.3.2.4) identifies the site parameters that must be obtained to design the repository and to develop the repository operating procedures to assure the non-radiological safety of the worker. The Excavation Investigations Study will provide the following types of information requested by Information Need 4.2.1: (1) demonstration of construction methods with emphasis on different lithophysae abundance, vitrification and geologic structure characteristics; (2) characterization of the exposed rock to ensure compatibility with the proposed design of the ground support system; (3) monitoring of the performance of the rock mass and ground support for different rock types and ground support systems; (4) evaluation of ground support performance with performance predictions; and (5) validation of the design models used to predict the performance of drifts and accessways.

Several parameters are required for the analysis of the underground repository (Information Need 4.4.7; SCP Section 8.3.2.5.7). In situ stress measurements will be performed as part of the Shaft Convergence Experiment and in the Demonstration Breakout Rooms Experiment as part of Study 8.3.1.15.2.1: Characterization of the Site Ambient Stress Conditions. Measurements performed during the Demonstration

Breakout Rooms Experiment will provide information on the response of the rock mass to drill and blast mining techniques and to the ground support system used. The Sequential Drift Mining Experiment will provide data on fracture joint density, orientation and spacing which are required by Information Need 4.4.7. Additionally, this experiment will enhance the data base required for the validation of models that provide a measure of the design performance. The Excavation Investigations Study is called for specifically in SCP Section 8.3.2.5 which lists those studies required for design and performance analyses.

SCP Section 8.3.1.15 requires in situ rock mass properties for examining the validity of extrapolating laboratory properties to in situ conditions. Additionally, observations of the behavior of underground excavations are required to evaluate the response of the welded, devitrified Topopah Spring Member (units TSw1 and TSw2) to the excavation process and to validate the constitutive models being developed to predict the mechanical response of the rock mass. Each of the experiments planned for the Excavation Investigations Study will provide data that will be used to develop, test and eventually validate the rock-mass constitutive models.

Information Need 1.11.5 (SCP Section 8.3.2.2.5) requires that the damaged zone around the drifts be adequately characterized at the time of repository closure. Displacement measurements around the periphery of the Exploratory Shaft and repository-size drifts in each of the Excavation Investigations Study experiments will be used to delineate the extent of damage induced by excavation. Additionally, permeability and compressional velocity measurements performed in the Sequential Drift Mining Experiment will be used to estimate the rock mass changes occurring in the stress altered region.

1.2.2 Regulatory Requirements

This Study will provide some of the information required to demonstrate compliance with several key regulations outlined in

10 CFR Part 60 "Disposal of High-Level Radioactive Wastes in Geologic Repositories: Licensing Procedures". These regulations form the basis for the guidelines outlined in 10 CFR Part 960 "Nuclear Waste Policy Act of 1982; Final Siting Guidelines". Performance objectives as stated in 10 CFR Part 60 require demonstration that: (1) waste retrieval shall be feasible starting at any time up to 50 years after waste emplacement begins (60.111); and (2) that the overall system performance of the geologic repository shall be such as to ensure that releases of radioactive material to the accessible environment conform to applicable Environmental Protection Agency requirements (60.112). The Excavation Investigations Study experiments will provide a data base that can be used to refine and validate the rock-mass constitutive models that will be used to evaluate the design of the underground facility. This design is intended to permit retrievability during the pre-closure period. These experiments will also characterize the stress altered region and assess its extent so that performance assessment calculations may incorporate variations in the rock mass properties throughout this region.

The Nuclear Regulatory Commission (NRC) requires that the underground facility be constructed in a geologic medium that has geomechanical properties which will permit the design of underground openings that will remain stable through permanent closure (10 CFR 60.122). Potentially adverse conditions outlined in 10 CFR Part 960.5-2-9; Rock Characteristics include in situ characteristics that could necessitate extensive maintenance during repository operation and closure and in situ conditions that require engineering measures beyond reasonably available technology during the construction of the underground facility. Displacement, in situ stress and rock bolt load cell measurements performed in the Excavation Investigations experiments will be used to assess the potential for stability of the underground openings through permanent closure. Openings will be designed to minimize deleterious rock movement and fracturing of overlying or surrounding rock and the design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for ground water (10 CFR 60.133). Evaluation of excavation efficiency and measurements of permeability and compressional velocity planned for the Sequential Drift Mining Experiment will be used to address these regulations. A Safety Analysis Report (SAR), which must be prepared for submittal with the License Application, will contain a description and assessment of the proposed geologic repository operations area that might influence design and performance. In the SAR (10 CFR 60.21), the NRC requires that "analyses and models which will be used to predict future conditions and changes in the geologic setting shall be supported by using an appropriate combination of methods such as field tests... which are representative of field conditions, monitoring data, and natural analog studies". This report will also document the geomechanical properties and conditions including pore pressures and ambient stress conditions (10 CFR 60.21). In addition, the SAR will provide an analysis of the performance of the major surface and subsurface design structures, systems, and components, to identify those that are important to safety. Monitoring the liner stress and in situ stress as well as delineating the extent of the stress altered region will provide some of the information required to perform this analysis.

The performance of major design structures that are required in 10 CFR 60.21 may affect the proposed shape and stabilization methods for varying rock conditions. The construction of repository-size drifts will be used to demonstrate that stabilization in the welded tuffs having varying lithophysae content and fracture densities is feasible. The requirement for minimizing the potential for deleterious rock movements and fracturing (10 CFR 60.133) are addressed by the estimates of the stress altered region and excavation efficiencies which provide supporting information on minimizing this potential. Adverse rock conditions that require complex engineering measures must be defined as required by 10 CFR 60.122.

A requirement of 10 CFR 60.21 states that in situ field tests must be performed to support the analyses and models used to predict future conditions. Some of these predictions for Yucca Mountain will be made using the constitutive models for rock mass mechanical behavior which will be assessed using data collected in the Excavation Investigations Study experiments. Developing excavation techniques which limit the potential for creating preferential pathways for radionuclide transport (10 CFR 60.133.f) will be addressed using data obtained to define the extent of the stress altered region. Permeability measurements obtained during the Sequential Drift Mining Experiment will be used to address, in part, 10 CFR 60.134.b that requires the use of materials and emplacement methods that reduce radionuclide transport through existing pathways.

2.0 Rationale for Excavation Investigations Study

Three experiments are planned for the Excavation Investigations Study that will emphasize monitoring the response of the rock mass to the excavation process. Each of these experiments is described in Section 3.0 of this Study Plan. The Shaft Convergence and Demonstration Breakout Rooms Experiments are in the final design stages. The Sequential Drift Mining Experiment will be modified as information is obtained from the other two experiments during construction of the Exploratory Shaft. The primary emphasis in each of these experiments is to measure rock mass displacements that will be used in the model validation process and to calculate the various parameters needed to describe the characteristics of the underground openings (e.g., stress distribution, convergence rate and magnitude, etc.). The techniques planned for this Study Plan (Section 3.0) emphasize the use of multiple point borehole extensometers (MPBXs) and rod extensometers which have been widely used and readily accepted by the mining and rock mechanics communities for monitoring rock mass response during and after construction of underground openings (e.g. Bieniawski and Maschek, 1975; Franklin, 1977; Brady and Brown, 1985; and others).

2.1 Rationale and Justification for Excavation Investigations Experiments

2.1.1 Model Validation

The primary objective of the Excavation Investigations Study is to obtain a data base that will be used in the development and validation of the rock-mass constitutive models for predicting the rock mass deformational behavior in response to stresses induced by excavation and thermal loading. Although these three areas (i.e., data collection, model development and model validation) are closely related, the rationale presented in this Study Plan emphasizes the collection of data to support the latter areas and only briefly summarizes, with appropriate references, the model development effort and the validation process.

Recent attempts to model the rock mass response to excavation and to provide estimates of the measured displacements have had limited success (Heuze et al., 1981; Heuze, 1984; Butkovich, 1985; Butkovich and Patrick, 1986; Morgan et al., 1985; Munson and Fossum, 1986; Wawersik and Morgan, 1987). Discrepancies between measured and calculated closure rates in bedded salt at the Waste Isolation Pilot Plant (WIPP) suggests that the models employed to predict closure do not fully encompass the physical phenomena controlling closure in salt. Wawersik and Morgan (1987) identified several conceivable sources of error that may contribute to the discrepancies between measured and predicted convergence values. Some of these sources of error include: (1) differences between the thermomechanical behavior of salt core in laboratory tests and of salt masses in situ; (2) errors in generalizing one- and two-dimensional axisymmetric thermomechanical measurements on salt to three dimensions; (3) ommission of instantaneous plastic strains; (4) inaccuracies in stratigraphic idealization; and (5) incorrect descriptions of transients and history effects.

Similar comparisons performed in fractured granitic rock at Climax also show significant disparities between predicted and measured closure trends and magnitudes (Heuze et al., 1981a,b; Heuze, 1984; Butkovich, 1985; Butkovich and Patrick, 1986). The predictions at Climax indicate horizontal and vertical closure of the drifts and lateral expansion of the pillars. Field measurements indicate lateral contraction of the pillars and inconsistent drift closure data. The apparent discrepancies between the measured and calculated closure rates at both WIPP and Climax demonstrate the difficulties in obtaining reasonable concurrence between the measured and calculated rock mass response and in identifying and accurately representing the physical phenomena that control rock mass deformation. The staged, iterative experimental and modelling approach presented in this Study and the approach to model development discussed in Sections 6.4.2 and 8.3.2 of the SCP are intended to provide the capability to make acceptable a priori predictions that accurately reflect the nature and magnitude of fractured rock mass deformational behavior.

Both empirical and numerical modelling approaches will be used in jointed, welded tuff to predict the rock mass response to excavation. Empirical approaches rely on rock mass classification methods, which are based on experience, to predict stability and to design ground support systems. This approach does not, however, take into account the effects of heat.

The numerical modelling methods are founded on constitutive laws that mathematically describe the physical processes of fractured tuff deformation. The models currently being considered approximate the mechanical response of the rock mass as an elastic, elastic-plastic, or compliant jointed media (SCP Section 6.4.10 and 8.3.2; Thomas 1980, 1982; Chen 1986, 1987; Blanford et al., 1987). These models will incorporate an understanding of the physics of the deformation process to provide a quantitative assessment of the stress state and the displacements resulting from both mechanically and thermally induced stresses. Thus, the numerical models provide insight into the underground design that is not possible using empirical techniques alone.

An elastic constitutive model has been used to approximate the measured deformation of densely welded, jointed tuffs in G-Tunnel (Zimmerman et al., 1986). In this application the elastic constants that serve as input parameters to the model were modified to account for the fractured rock mass and to provide a reasonable approximation of the measured deformation. The ubiquitous joint model (Thomas, 1980) has also been used to evaluate the state of stress in jointed, welded tuff. This model incorporates an elastic-plastic joint shear behavior and assumes a single dominant fracture orientation and spacing. This assumption may restrict the application of this model to specific areas of the underground facility characterized by extensive, regularly spaced fractures. The compliant joint constitutive model (Thomas, 1982; Chen, 1986, 1987; Blanford et al., 1987) incorporates a continuum-based technique to average the discontinuous displacements across fracture planes within a representative elementary volume and a constitutive description based on the linear elastic behavior of the matrix material and nonlinear normal and shear behavior of the joints. In the compliant joint model, material properties are required for both the matrix and the fractures. The model is formulated in three-dimensions but is currently limited to two-dimensional implementations in finite element codes, orthogonal joint sets (Chen, 1987) or multiple joint sets (4 maximum) of arbitrary orientation (Blanford and Key, 1987), and noninterfering block responses. Data obtained from G-Tunnel (Zimmerman et al., 1987; 1988) and from Yucca Mountain will be used in an attempt to relax these restrictions and improve the capability of this model to describe multiple joint sets with variable orientations and characteristics.

The experiments planned in this Study emphasize measurements in planar geometries that are more easily modelled by two-dimensional codes and can be used to validate the physics controlling the rock-mass deformational behavior. Some measurements will be incorporated into the Sequential Drift Mining Experiment to provide a limited data base for exercising the three-dimensional components of the numerical models. The In Situ Thermomechanical Properties Study (Study Plan 8.3.1.15.1.6) will include a Heated Room Experiment that emphasizes the collection of displacement measurements that should provide a sizable data base for comparison with the results of numerical simulations in three dimensions and provide a detailed comparison between the two- and three-dimensional approximations. The model validation process, discussed in Sections 6.4.2 and 8.3.2 of the SCP, is intended to assure that the physical model as embodied in the software is a correct representation of the physical process or processes. The formal validation process includes a series of steps that concludes with a comparison of experimental results and analytical predictions by a Peer Review Panel. The Excavation Investigations Study experiments are intended to provide bounding estimates for the displacement and stress data that will be compared with analytical predictions. This comparison will be used to assess if the measured and predicted results are of the same trend and if disparities between the measured and predicted data fall within the limits of the range of uncertainties arising from the combination of uncertainties in the data used as input for the calculated response and uncertainties in the measured field data. Failure to validate the rock-mass constitutive models may require that performance allocation goals be reevaluated and that additional data acquisition and characterization studies be initiated. The Peer Review Panel is expected to provide input to the direction any additional activities should take.

2.1.2 In Situ Monitoring of Rock Mass Performance

The primary objective of any underground excavation design is to utilize the rock mass itself as the principal structural support material and minimize the need for additional ground support (Hoek and Brown, 1980). To achieve this objective it is necessary to minimize the effects of the excavation process on the surrounding rock and to develop an understanding of the geological and geomechanical characteristics of the rock mass. An understanding of the effects of excavation on the in situ stress state and the interaction of the underground support system with the redistributed stresses are necessary to develop an underground facility that will remain serviceable throughout the required operational period.

Monitoring the behavior of underground excavations during and after the construction process is the most reliable means of developing an understanding of the behavior of the rock mass for the design and construction of underground structures (Bieniawski and Maschek, 1975). Information obtained during a monitoring program will be used to check the validity of the assumptions, conceptual models, and rock mass properties used in design considerations. Additionally, this information will contribute to worker safety by providing data to delineate excessive ground deformations or loads imposed on the repository support elements. Time-dependent deformational behavior resulting from possible long-term physicochemical changes may influence the stability of underground excavations. Monitoring programs can be used to identify these time-dependent changes if they occur so that appropriate remedial programs can be developed.

The observational method (Peck, 1969) which emphasizes field observations of the performance of structures is central to the general practice of geotechnical engineering. Brady and Brown (1985) summarize the types of measurements generally incorporated in a monitoring program associated with the construction of an underground facility. This program emphasizes two basic physical responses, displacement and pressure, that are then used to calculate forces and stresses using available numerical models and estimated material properties. Bieniawski and Maschek (1975) have shown that convergence magnitude and rate measurements are essential for estimating the adequacy of underground support systems.

The in situ stress state which exists in an undisturbed rock mass is related to the weight of the overlying strata and the geologic history of the rock mass. An underground excavation will disturb the in situ stress field and may induce stresses that exceed the rock mass strength, leading to failure of the rock adjacent to the excavation boundary and to instabilities that become evident as gradual closure, roof falls, slabbing, and, in the worst case, even rockbursts (Hoek and Brown, 1980). Prior to calculating the induced stress state associated with these openings, the undisturbed in situ stress state must be determined using in situ measurements to minimize the uncertainty associated with the calculated, induced stress values (Hoek and Brown, 1980). Although the stress distribution around an isolated underground opening in a linear elastic, homogeneous, isotropic material is independent of the size of the opening, the stability of the opening is still largely contingent on the ratio of the excavation size to the representative size of the blocks composing the jointed rock mass. Thus, although the theoretical stress level may remain constant as the size of the excavation increases, the actual stability of the opening probably decreases. This emphasizes the significance of a detailed geologic characterization program that is integrated directly with the geomechanical testing program.

A number of other factors can influence the distribution of the stress state and hence, possibly the stability of the underground facility. The shape, orientation, and distribution of the openings can have a significant effect on the induced stress distribution as can the size, shape and distribution of the pillars and geologic structure (Hoek and Brown, 1980). Each of these factors must be considered when defining the expected induced stress state so that the response of the rock mass can be adequately predicted and a design for the underground facility developed that helps to ensure stability.

A detailed geologic characterization study is a fundamental component of any in situ monitoring program. Wilder et al. (1982) suggest that the geologic characteristics of the rock mass are possibly the most significant factors that influence MPBX measurements. This may be particularly true in fractured rock where measurements may be influenced by joint closure, rigid block rotation and/or translation. Zimmerman et al. (1987; 1988) performed convergence measurements in welded tuffs located in G-Tunnel using a tape extensometer and MPBXs. Convergence magnitudes along the length of a 30 m long repository-size drift varied by a factor of two, which they attribute, in part, to variations in local geology. Detailed geologic characterization studies are required at each geomechanical measurement station within the shaft or drift prior to the installation of geomechanical instrumentation to enhance the interpretation of data. Standard mapping or photogrammetric techniques should be employed to map the shaft and drift walls; cores and instrumentation holes will be examined to delineate variations in the rock characteristics and to select borehole instrumentation locations.

Franklin (1977), Pratt et al. (1979), Brady and Brown (1985) and others have described the requirements for a monitoring system that will help to ensure safety during the construction phase and check the assumptions used in the underground design. The type of monitoring program developed for a particular geologic medium is contingent largely on the characteristics of the rock mass and the objectives of the construction project. In each project however, a number of specific measurements are usually obtained with several different types of instruments that are capable of providing the information required to achieve the stated objectives. An integral part of any instrumentation program is the incorporation of a suite of instruments that are capable of obtaining redundant measurements to enhance data interpretation and to ensure that data will be obtained despite potential instrument failure.

Two types of basic physical responses, displacement and pressure, are measured in most monitoring programs (Brady and Brown, 1985) and have been incorporated into the Excavation Investigations experiments. Displacement of the rock associated with excavation of the underground structure is generally monitored using MPBXs, rod extensometers, and borehole inclinometers. Rock pressures and loads on the support system are calculated using borehole deformation gauges and stress meters, hydraulic pressure cells, and rock bolt load cells. Data obtained using these instruments will play a fundamental role in enhancing our understanding of the response of the rock mass to the excavation process in the underground facility.

2.2 Rationale for the Location, Number and Alternatives for Excavation Investigations Experiments

2.2.1 Number and Location of Experiments

The location of each Excavation Investigations experiment within the Exploratory Shaft Facility has been selected to characterize the range of rock mass characteristics most likely to be encountered during the development of the underground facility. The geologic variability anticipated within the underground facility results primarily from changes in fracture characteristics and lithophysae content. Each reference geomechanical and geological unit within the Topopah Spring Member (Ortiz et al., 1985) above the repository level will be characterized to assess the effects of these variations on the stability of the underground openings.

The number of experiments planned in this Study are considered the minimum necessary to obtain the data base required for validating the constitutive models, to provide in situ geomechanical parameters in support of site characterization activities and to monitor the performance of repository-size underground openings. Each experiment includes a series of measurement stations that will be used to evaluate the variability within the major geologic units examined.

A staged approach has been adopted for obtaining a data base necessary for validating the rock-mass constitutive models. This approach begins by obtaining data in the Shaft Convergence and Demonstration Breakout Rooms Experiments that are located in the various geological and geomechanical units which have characteristics that may be encountered in the underground facility. These data will be used to refine the models and to perform a preliminary assessment of the effects of geologic variability on the stability of the underground openings. As data become available from these two experiments a comparison of the measured and predicted response of the underground openings to the excavation process will be completed. These results will be compared and additional revisions to the models will be completed if necessary. An additional evaluation of the rock-mass constitutive models will then be performed using the data base obtained during the Sequential Drift Mining Experiment. This experiment will be performed in an area within the Exploratory Shaft Facility which is expected to be representative of the geological and geomechanical characteristics expected at the repository horizon (Nimick et al., 1988). As a direct result of this approach, the models should, by incorporating the appropriate geomechanical parameters determined for the geological units encountered, accommodate the range of geological conditions that are expected to occur within the underground facility.

A significant amount of experience gained during the excavation and stabilization of repository-size openings in the various rock types likely to be encountered underground will assist in minimizing the damage induced during the excavation of the underground facility and maximizing the efficiency of the mining process. Specific ground support requirements that exist for certain rock types or structural features need to be confirmed early in the construction phase to minimize their impact on scheduling and budget. Performance of the underground openings needs to be evaluated in repository-size drifts that are of sufficient length to minimize end effects resulting from the termination of the opening and the effects resulting from the interaction of other underground openings. Each of these concerns requires a substantial amount of excavation which will be performed, in part, to fulfill the objectives of the Excavation Investigations Study experiments.

2.2.2 Alternatives for Excavation Investigations Study Experiments

The staged approach described in Study Plan Section 2.2.1 for obtaining data required to validate the rock-mass constitutive models is intended to provide an understanding of the interrelationships between geologic variability and the geomechanical response of fractured welded tuffs. This understanding will be developed in an iterative manner, beginning with the experiments that evaluate the rock mass response to excavation in each major geologic unit within the Topopah Spring Member (i.e. Shaft Convergence and Demonstration Breakout Rooms Experiments) and culminating with the detailed geologic characterization and geomechanical measurement program that will be performed as part of the Sequential Drift Mining Experiment. The Sequential Drift Mining Experiment will instrument and characterize the rock mass prior to excavation and monitor the rock mass response during and after excavation. This information will be used to evaluate the time-dependent behavior of the rock mass within a well-defined geologic setting.

Other types of experiments will supplement the information obtained by the Excavation Investigations Study experiments by providing specific types of similar data (e.g. displacement data) in other regions of the underground facility (In Situ Design Verification Study Plan; 8.3.1.15.1.8). Convergence measurements will be performed within the long drifts planned to intersect Ghost Dance Fault and the zone of imbricate faulting. These measurements will be used to develop a substantial data base, containing drift convergence rates and magnitudes, obtained after the mined face has advanced to, or beyond, the measurement station location. Additionally, convergence data will be obtained in the areas proximal to the major structural discontinuities associated with Ghost Dance Fault and the zone of imbricate faulting. These data may be useful for designers to establish appropriate stand-off distances and adequate stabilization techniques within these zones. The configuration of these drifts, however, may not permit instrumentation to be installed prior to the onset of excavation which would preclude the collection of data related to the initial rock mass response to excavation. A detailed understanding of the interrelationships between geologic variability and the geomechanical response of the rock mass beyond the perimeter of the underground opening may be difficult to develop relative to the quality of information obtained in the Sequential Drift Mining Experiment. Despite these constraints, convergence measurements in and around the major structural discontinuities will be considered as plans for the long drifts become better defined.

Several similar activities will be completed in each of the experiments planned for the Excavation Investigations Study. These activities are largely related to defining the extent of the stress altered region and to monitoring convergence rates and magnitudes. Several techniques will be employed to define the extent of the stress altered region. Variations in rock mass displacements, and changes in the stress state, permeability and compressional velocity will be used to delineate the blast damaged zone and the stress redistribution zone. Convergence rates and magnitudes will be established using displacements obtained with MPBX's, tape extensometers, and borehole inclinometers.

The Goodman jack, used to obtain estimates of borehole modulus, is also being considered for evaluating the extent of the stress altered region. The technique has only been used in a limited manner within fractured welded tuffs and may be influenced by joint spacing. In addition, the volume of rock energized with the Goodman jack is limited and may only be used to provide profiles of relative changes in the borehole modulus. However, results from Patrick et al. (1985) indicate that a statistically significant decrease in borehole modulus occurs very near the excavation surface (< 0.5 m) in fractured granitic rock which should correspond to the interval containing the blast damaged zone in the underground facility. Further evaluations of this technique will occur to determine its reliability in a fractured geologic medium prior to incorporating the technique into any of the Excavation Investigations experiments.

High frequency rock noise (acoustic emission) generated from changing stress conditions has been used to successfully monitor the structural stability of underground mining operations (Repsher and Steblay, 1985; Majer et al., 1981; Majer and McEvilly, 1985). Acoustic emission monitoring has been particularly useful in predicting rockbursts in overstressed rocks with high elastic and strength properties. Recently, Hardy (1984) and others have begun to detect and process low-level signals associated with soils and soft rocks such as salt. Application of acoustic emission in these geologic media necessitates a higher degree of monitoring system optimization and additional care in signal processing than normally required with higher energy events associated with high stress regimes.

The acoustic emission technique has been considered for monitoring rock mass stability in the Demonstration Breakout Rooms and Sequential Drift Mining Experiments. Low-level acoustic emission events may occur in the facility after the ground support system is installed. The intensity and number of acoustic emission events due solely to the redistributed stress field is not expected to provide a sufficient data base to augment the other Excavation Investigations Study activities planned. Unless the stress conditions induced by the orientation of the underground facility can be greatly increased without introducing a thermal source or unless time-dependent deformation processes related to physicochemical changes are occurring, the acoustic emission technique has very limited application in the Excavation Investigations Study experiments. Utilization of acoustic emission techniques will probably be incorporated into the thermomechanical experiments planned for the Exploratory Shaft Facility.

Petite sismique has been used by a number of investigators to determine the field deformation modulus of the in situ rock mass (Schneider, 1967; Bieniawski, 1978; Heuze et al., 1981b; Zucca, 1984) in a number of different rock types. The petite sismique technique involves energizing the rock mass to create a shear wave and then recording the signal at some location up to tens of meters away. The dominant frequency of the recorded shear wave is measured and the modulus calculated using an empirical relationship developed by Heuze et al. (1981b). The technique is relatively inexpensive and easy to perform compared with other techniques and provides information from a large volume of rock. However, the work by Zucca (1984) indicates that the characteristics of the source and path length, the frequency response of the rock mass, and the attenuation effects as the distance between the source and receiver increase be well-defined to provide a high degree of confidence in the reproducibility of the results. As this technique continues to be developed it may have definite applications in the Sequential Drift Mining Experiment and provide a useful source of information for comparison with the modulus of deformation data that will be obtained in the Rock Mass Mechanical Properties Study Plan. However, at the present time, the use of petite sismique is not planned because of the uncertainties discussed above.

The in situ stress state is required to design stable underground openings. Overcore stress measurements will be performed as part of the Shaft Convergence Experiment and in the Demonstration Breakout Rooms as part of the Characterization of Site Ambient Stress Conditions Study Plan. Zimmerman and Vollendorf (1982) present test results and summarize the problems encountered with the use of this technique in fractured welded tuff. Other techniques available for determining the in situ stress state include the anelastic strain recovery method which utilizes oriented core to predict the in situ stress (Teufel, 1981) and hydraulic fracturing (Warpinski et al., 1981) which is performed in boreholes with a packer system. The anelastic strain recovery method has not been performed in welded tuffs, although measurements performed in non-welded tuffs (Teufel, 1981) indicate that the strain relaxation is uniform with time and that strain orientations may provide an accurate determination of the principal horizontal in situ stress direction. Prototype tests will be conducted in G-Tunnel welded tuffs to evaluate the reliability of the anelastic strain recovery method for this type of geologic medium. If G-Tunnel tests are favorable this technique will be incorporated into the Excavation Investigations experiments.

A limited amount of hydraulic fracture data have been obtained in fractured welded tuffs. Results from Rainier Mesa presented by Warpinski et al. (1981) indicate that natural fractures in the welded tuffs caused significant offsets in the induced fractures, resulting in severe fluid loss. Results presented by Stock et al. (1985) indicate that after the initial shut-in pressure, preexisting fractures in Yucca Mountain welded tuffs were reopened rather than new fractures created. Additionally, difficulties determining the exact orientation of the induced fractures limited the level of confidence in the determined value of the least horizontal stress. Requirements to limit the amount of fluid injected into the rock mass surrounding the Exploratory Shaft Facility and the difficulties encountered in interpreting this type of data in fractured and unsaturated welded tuffs will preclude using hydraulic fracturing as part of the Excavation Investigations Study.

2.3 Constraints on Excavation Investigations Study

2.3.1 Potential Impact on the Site

The potential impacts related to the construction of the Exploratory Shaft on the site are discussed in Section 8.4 of the SCP. No additional impacts on the site are expected as a result of the experiments conducted in this Study. Only a minimal amount of excavation is required for the Excavation Investigations experiments as compared to that required for the Exploratory Shaft Facility. The proposed measurement stations in the Shaft Convergence Experiment are located within the Exploratory Shaft itself and do not require additional excavation. The Demonstration Breakout Rooms and Sequential Drift Mining Experiments will require specific excavations, but in both experiments the amount of material extracted is very small. The permeability measurements conducted as part of the Sequential Drift Mining Experiment require a minimal amount of water that will be regulated and monitored to limit any impact on the site. No other impacts on the site should occur as a result of the experimental work planned in this study.

2.3.2 Repository Simulation and Scale of Phenomena

The model validation process requires that a representative volume of rock be subjected to experimental conditions approaching or exceeding those expected in the underground facility. Ideally, these conditions will result in stress levels and displacements that exceed the maximum anticipated for the repository while monitoring the rock-mass response during the model validation process. Repository-size (cross-sectional dimensions) excavations will be used in the Excavation Investigations experiments to approximate those conditions anticipated in the underground facility. The exact dimensions will be determined as the design for the underground facility proceeds. However, in an effort to increase the induced stresses and measurable displacements in welded tuffs with subvertical to vertical fractures the widest repository-size opening will be used in the Demonstration Breakout Rooms and Sequential Drift Mining Experiments. Current design plans (MacDougall et al., 1987) show the dimensions of the widest opening (i.e., Tuff Main) are the same for both the vertical and horizontal emplacement concept. The lengths of the drifts in the Demonstration Breakout Rooms Experiment will be designed so that the drift mid-sections will be subjected to stress levels that approximate those envisioned for the underground facility without being influenced by the Exploratory Shaft or end effects resulting from the termination of the rooms (Petney, 1986). Repository-size drifts will also be used in the Sequential Drift Mining experiment to evaluate the response of the rock mass to the excavation process. The length of the drifts (approximately six times the width) are adequate to minimize end effects and the spacing between the access drift and instrumentation drift will be designed so that displacements meet or exceed those expected in the underground facility.

Variations in the rock mass thermal response will be evaluated using experiments planned in the In Situ Thermomechanical Properties Study Plan. Temperature-dependent conduction appears to be the dominant heat transfer mechanism for unsaturated tuff (Zimmerman et al., 1986). The rock mass thermal responses from the heat source will be analyzed separately from the mechanical responses and input into the mechanical analyses to calculate the thermomechanical response (SCP Section 8.3.2). Experiments planned in the In Situ Thermomechanical Properties and Excavation Investigations Study Plans are expected to simulate the major types of thermomechanical behavior that are likely to occur within the repository.

2.3.3 Time Available for Model Validation Considerations

The primary data collection period for each of the Excavation Investigations Study experiments is scheduled to occur over a period ranging from a few weeks to several months.

A limited number of measurement stations in this Study may, however, be used for long-term monitoring. The relatively short duration for each of the experiments should preclude any impacts on other Exploratory Shaft Facility construction or experimental activities, although the iterative process employed to validate the mechanical models could possibly result in delays that may impact project schedules.

The model validation effort consists of an iterative process that includes the collection of in situ displacement data and data obtained from interrelated Study Plans (see Table 1.1-1), continues with a comparison of the calculated and measured displacement results, and finally concludes with consultation and concurrence by an established Peer Review Panel (SCP Section 8.3.2.1.4.3). Several factors may contribute to delays in the validation process which could significantly impact project schedules. In the Sequential Drift Mining Experiment, displacement data will be obtained in the instrumented drift at several stations during and after the excavation process. Vertical displacement data will be analyzed and compared for each of the measurement stations to assess if characteristic data have been collected for estimating representative displacement values for the entire drift. If these representative values cannot be determined, additional geological characterization studies and an assessment of the adequacy of the instrumentation type and placement will be required prior to comparing the measured results with the results predicted using the mechanical model. If the lack of uniformity is attributed to instrumentation drift or calibration problems then additional calibrations will be performed and an assessment of the vertical displacements will be repeated. If the results indicate that significant geologic complexity exists then additional detailed geologic characterization will be required. After establishing representative measured displacement values a comparison will be made between the measured and calculated values. The results of this comparison will be used by the Peer Review Panel to determine if the comparison of results are valid using the guidelines in SCP Section 8.3.2.1.4.3.

2.3.4 Differentiation of Stress Altered Region

The stress altered region consists of the blast damaged zone and the stress redistribution zone. In controlled blasting, the blast damaged zone is generally limited to a radial distance of a few tenths of meters to possibly a meter from the perimeter of the opening (Holmberg and Persson, 1980). Induced stresses associated with the stress redistribution zone are generally considered negligible beyond three opening diameters from the perimeter (St. John, 1987). The stress in this zone may be higher or lower than the original in situ stress depending on the shape, orientation, and distribution of the underground openings and on the initial stress tensor.

Delineating the extent and nature of the stress altered region and the relationships between the blast damaged zone and the stress redistribution zone can have significant ramifications for modelling the mechanical, thermal, and hydrologic characteristics of the rock mass around the openings. Rocks located within the blast damaged zone would generally have a lower modulus of deformation, rock quality designation, compressional and shear wave velocities and higher permeabilities (Hustrulid and Ubbes, 1982). Variations in rock mass displacements, compressional and shear wave velocities, and permeabilities that will be measured in the Sequential Drift Mining Experiment will occur as a result of the stress change associated with the stress redistribution zone. However, depending on a number of factors including localized geology, these changes may either accentuate the changes that occur in the blast damaged zone or possibly even lead to an apparent reduction in the radial extent of the blast damaged zone. Analyses by Petney (1986) show that in the Demonstration Breakout Rooms Experiment the introduction of a blast damaged zone into the calculation increases the displacements of the excavation boundaries, lowers the stress at the excavation surface, and produces a stress peak in the rock mass located outside the blast damaged zone. Although several different techniques will be employed in an attempt to distinguish between the effects of each of these zones on the characteristics of the rock mass around the opening, information presently available would suggest that developing these relationships in jointed welded tuffs are constrained by the available instrumentation and analytical techniques. These techniques should, however, provide the necessary data to describe the combined effects of these changes on the rock mass located within the stress altered region.

2.3.5 Rock Mass Changes Prior to Instrumentation

Each of the experiments planned for the Excavation Investigations Study have been designed so that changes occurring in the rock mass prior to instrument installation are minimized. A finite element analysis which incorporates an axisymmetric geometry and elastic-plastic material model (Labreche, 1985) has been used to estimate changes in the stress state and the amount of shaft closure that occurs prior to the shaft face reaching the measurement station. Results of the stress calculations indicate that the stress measured 4.6 m and 10 m ahead of the shaft face will be within 20 % and 2 %, respectively, of the actual in situ stress. When the uncertainties associated with current technologies for measuring in situ stress and the variation in stress caused by variable geology are considered, the measured stress values can be considered representative of the in situ stresses.

Estimates of shaft convergence (Labreche, 1985) indicate that only 25 % to 35 % of the total rock displacement around the shaft will be recorded at the measurement station after instrument installation. These calculations also indicate that 75 % of the total rock displacement could be measured if instrumentation could be installed 2.5 m ahead of the advancing face. Data obtained in the Sequential Drift Mining Experiment will be collected before, during, and after the mined face advances beyond each measurement station. These data will be compared with the predictions of total displacement that are based on elastic-plastic material models to determine if the initial displacement history measured in situ is comparable to that predicted. These comparisons will compose one component of the validation process.

2.3.6 Interrelationships With Other Studies

The experiments planned in the Excavation Investigations Study will contribute to a data base that will be used to validate the rock-mass constitutive models. Data from several other studies will also contribute to the data base used to validate these models. These studies will characterize the intact rock and fractures, and enhance our understanding of the rock mass response to heating and to the excavation process. Specifically, the experiments planned in these studies (Table 1.1-2) will be used to improve the capability to predict the rock mass response and help to ensure stable underground openings throughout the waste retrieval period.

Changes in fracture characteristics and variations in lithophysae content can significantly alter the rock mass response to the excavation process. Results from the Characterization of the Structural Features Within the Site Area Study, the Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area Study, and Fracture Studies of Intact Rock Study will characterize these changes and supplement the interpretation of data obtained in the Excavation Investigations Study.

The stability of the underground openings is contingent on several factors including the rock mass response to induced thermal and mechanical stresses. The In Situ Thermomechanical Properties Study experiments will be used to validate the thermal model which will be combined with the mechanical models to predict the long-term stability of the underground facility. The In Situ Design Verification Study will monitor drift stability and the performance of the ground support systems in variable geologic conditions. These data will complement the data obtained in this study for validating the rock-mass constitutive models. A detailed evaluation of excavation efficiency which includes varying the mining techniques for different underground conditions will be conducted as part of the In Situ Design Verification Study. This evaluation will develop a substantial data base that will supplant the limited information obtained on excavation efficiency in this Study.

Results from the Characterization of the Site Ambient Stress Conditions Study will be used to obtain in situ stress values in several locations with variable fracture density and lithophysae content using the overcore stress and anelastic strain recovery techniques. These data will be combined with stress measurements obtained in the Shaft Convergence Experiment to delineate local variations in stress within the Topopah Spring Member.

Permeability measurements performed primarily to evaluate the extent of the stress altered region will also provide insight into the differences in permeabilities determined using air and water. These data will complement hydrologic studies planned for the Exploratory Shaft Facility.

A limited amount of in situ geomechanical data will be obtained in the Excavation Investigation Study experiments that can be used to develop and evaluate scaling relationships for extrapolating from laboratory-derived data to in situ conditions. Permeability and compressional wave velocity measurements obtained during the Sequential Drift Mining Experiment will contribute to the data base that will be used to develop these scaling relationships. Data obtained in the Rock Mass Mechanical Properties Study, the Laboratory Determination of Mechanical Properties of Intact Rock Study, and Fracture Studies of Intact Rock Study will be used to examine and develop scaling relationships for comparing strength and modulus of deformation parameters and to provide input parameters for exercising the models.

2.3.7 Statistical Relevance of Excavation Investigations Study Data

The experiments planned for the Excavation Investigations Study will not provide a statistically valid data base for the in situ rock mass characteristics of the Topopah Spring Member. However, all available site characterization data will be used to locate each experiment in those intervals of the Topopah Spring Member that appear representative of the conditions expected at the repository horizon or that bound the conditions expected to be encountered. The approach to developing a statistically valid data base that has been adopted is to sample and test the major geomechanical and geological units in situ and develop scaling relationships for extrapolating from laboratory determined values to the in situ environment. A limited suite of data (i.e., compressional velocities, permeability) will be obtained in the Excavation Investigations Study to develop or extend scaling relationships which will be derived from experiments performed in the Rock Mass Mechanical Properties Study and the Laboratory Determination of Mechanical Properties of Intact Rock Study. The approach for developing scaling relationships is continuing to evolve and is discussed in SCP Section 8.3.1.15.

3.0 Description of Excavation Investigations Experiments

The Excavation Investigations Study is composed of three experiments that are intended collectively to provide much of the data required to validate the rock-mass constitutive models. The Shaft Convergence and Demonstration Breakout Rooms Experiments will provide the initial data required to evaluate and gradually refine the models that will be used to predict the deformational behavior and stability of the underground facility. The Sequential Drift Mining Experiment will provide a data base for a detailed evaluation of the models as part of the validation process. The design of this experiment is likely to change as data are obtained and analyzed from the other Excavation Investigations Study experiments and as the information base for the Topopah Spring Member improves as a result of other experiments performed during the construction of the Exploratory Shaft. Experimental Procedures will be written in conformance with Sandia National Laboratories Department 6310 Operating Procedures to direct the fielding of each Excavation Investigations experiment. The location of the Excavation Investigations Study experiments relative to the other experiments planned for the Exploratory Shaft Facility is described in Section 8.4 of the SCP.

3.1 Shaft Convergence Experiment

The Shaft Convergence Experiment is intended to quantify the influence of the in situ stress state and corresponding rock mass response as the Exploratory Shaft is mined and the concrete liner installed. The configuration of this experiment may be changed in response to modifications in the design of the Exploratory Shaft Facility. The experiment will be performed at three stations located at depths of about 80 m, 158 m (upper breakout level), and 311 m (main test level) within the Exploratory Shaft. The stations will be moved to other locations or additional stations will be added if, on the basis of the geologic structure and complexity, the objectives would be more readily achieved elsewhere. The station at 80 m was selected to define the stress state and rock mass response at the uppermost part of the Topopah Spring Member. The lower two stations will be used to evaluate the differences in the behavior of the welded tuff as a result of varying lithophysae content and fracture density.

A sequence of measurements will be performed at each station (Figure 3.1-1) to obtain the information necessary to calculate the horizontal stress state and liner contact pressure and estimate the extent of the stress altered region. The initial testing will consist of overcore measurements used to determine

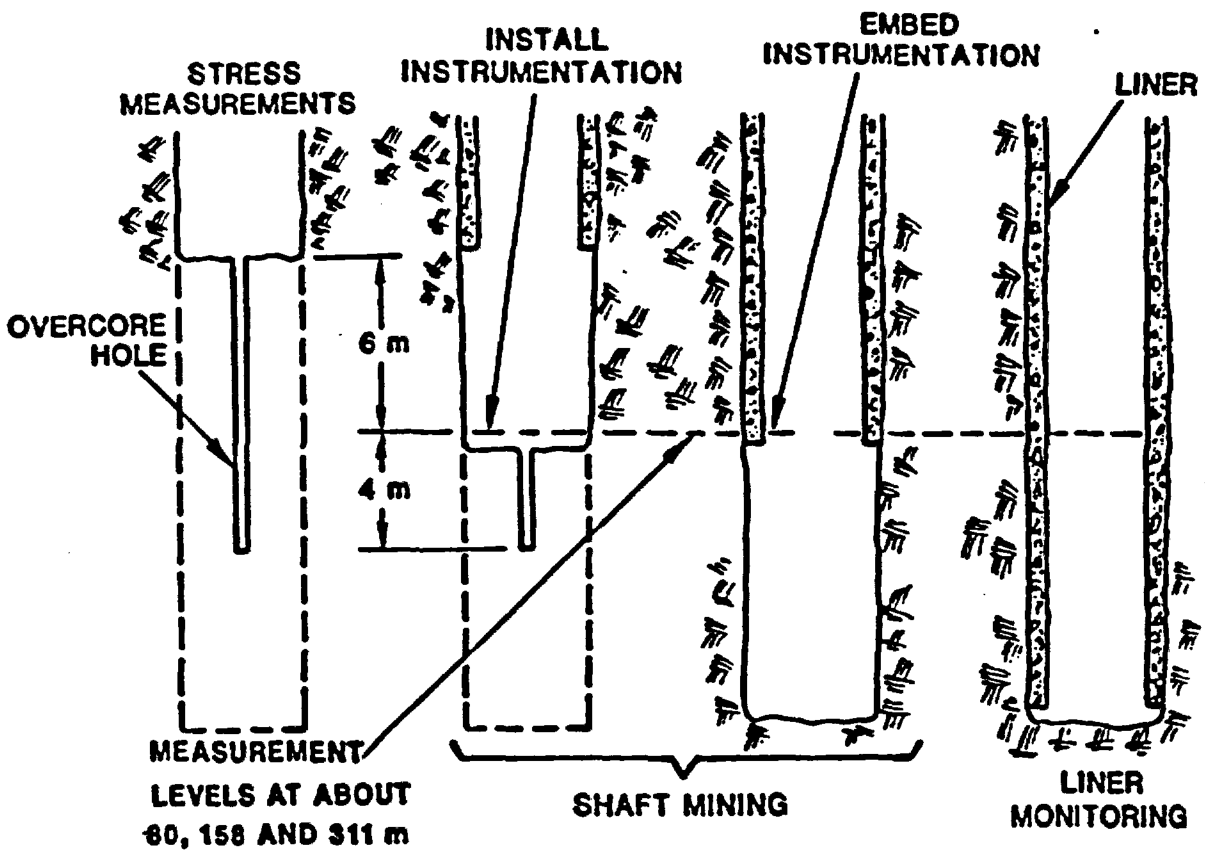

Figure 3.1-1: Measurement Sequence Planned For The Shaft Convergence Experiment.

the horizontal stress state at each measurement station. Mining will be stopped 6 m above each measurement station and a 10 m long vertical pilot hole will be diamond drilled down the center of the proposed shaft for installing instrumentation. The pilot hole will be examined using a borescope to delineate variations in fracture patterns, lithophysae content, and possibly borehole irregularities. Results reported for fractured welded tuffs in G-Tunnel (Zimmerman and Vollendorf, 1982) indicate that fracture spacing can influence overcore tests results. U.S. Bureau of Mines borehole deformation gauge (BDG) locations in the pilot hole will be carefully selected on the basis of the borescope data to limit the effects of fractures on the measurements. The first BDG will be installed at a depth of at least 4.6 m below the existing face with successive measurements to 10 m below the face. Vertical stresses calculated for these intervals should range from about 80 to 98 % of the in situ vertical stress (Labreche, 1985). The rock around the gauge will be carefully overcored while two-dimensional borehole deformation measurements are recorded (Hooker and Bickel, 1974). After overcoring, the core and the BDG will be transported to the surface laboratory where biaxial stress measurements will be performed. These measurements will be used to compute the elastic constants for the intact rock (Panek, 1966) which will be used in conjunction with the displacement data to calculate the horizontal stresses.

Shaft convergence measurements will be obtained at each measurement station using the six multiple point borehole extensometer (MPBX) heads spaced at 60^{o} intervals around the perimeter of the shaft as convergence anchors and using three sets of convergence anchors installed midway between the three sets of MPBX collars (Figure 3.1-2). Diametrical distances between opposite pairs of MPBX heads and convergence anchors are carefully determined with a rod extensometer prior to the continuation of shaft mining. As mining of the shaft proceeds beyond the measurement station, the unloading of the rock mass

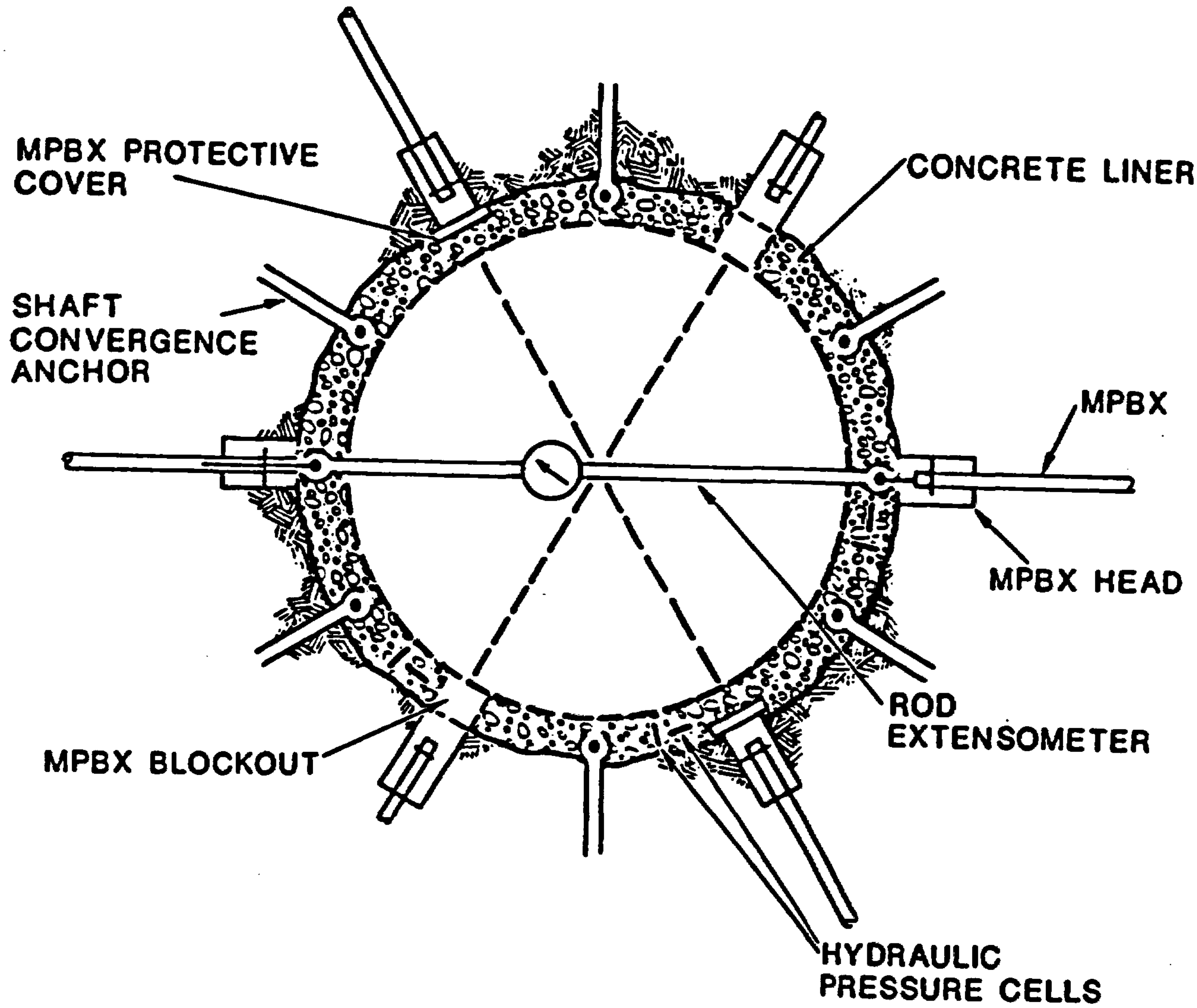

Figure 3.1-2: Schematic Of Instrumentation Locations Planned For Each Measurement Station In The Shaft Convergence Experiment.

during the mining process causes the rock walls to converge and the measured changes in the shaft diameter provide quantitative information on the response of the rock mass to excavation. Long-term convergence measurements will be continued to monitor any time-dependent changes in convergence rates or magnitudes.

In addition to the MPBX head located at the collar, each MPBX consists of a minimum of five anchors secured in the rock mass at 1 m intervals. A sixth anchor, which is used as a reference, is located at a nominal radial distance of 15 m from the MPBX head in undisturbed rock. Relative displacement measurements will be made between the MPBX head and the anchors as the mining of the shaft proceeds beyond the measurement station. In this case the rock mass deformations occurring at the anchor locations will be determined as a function of the position of the advancing mining face. Data obtained will be used to measure displacement variations with distance from the opening so that estimates of the stress altered region can be made as a function of the radial distance from the shaft wall at each measurement station.

Liner contact pressure measurements will be obtained by installing hydraulic pressure cells (HPCs) in the concrete liner. These cells will indicate the stress changes in the shaft liner. The HPC stress data are combined with the MPBX deformation data to provide the essential input for evaluating the rock/liner interaction. The MPBX measurements associated with the mining activities provide data that can be used to assess the possible loading of the shaft liner by the rock mass.

3.1.1 Quality Assurance Requirements and Technical Procedures

The quality assurance level assignment for each activity is summarized from the Exploratory Shaft Geomechanical Test Quality Assurance Level Assignments (QALA), NNWSI Element 1.2.6.9.2.3.S (Table 3.1.1-1). A QA Level of II is assigned to the Liner Contact Pressure Measurements because the shaft liner design has

Table 3.1.1-1: Quality Assurance Level Assignments For Each Activity Planned In The Shaft Convergence Experiment.

Activity	Quality Assurance Level Assignment
Horizontal Stress Measurements	I
Estimate of Stress Altered Region	I
Liner Contact Pressure Measurement	II

a major impact on only the non-radiological structural reliability of the engineered system. All work will be performed in accordance with the Sandia National Laboratories Quality Assurance Program Plan (1986).

The Shaft Convergence Experimental Procedure will describe the operational and technical procedures required to fulfill the experiment objectives. Technical procedures for each of the methods employed during the Shaft Convergence Experiment (Table 3.1.1-2) will be completed at least six months prior to the start of excavation.

3.1.2 Accuracy and Precision

The accuracy and precision of the Shaft Convergence Experiment data is largely contingent on the amount of convergence that occurs prior to instrument installation and the capability of calculating reasonable estimates of the convergence that has occurred prior to recording data. Finite element analyses that incorporates elastic-plastic material properties and an axisymetric geometry (Labreche, 1985) indicate that the calculated in situ stress values will be within 20 % of the actual in situ values. Approximately 60 % of the total displacement associated with convergence of the shaft will occur prior to instrument installation. Attempts to install MPBXs or borehole deflectometers ahead of the advancing face are being considered, if practical, to minimize the amount of unrecorded displacement occurring prior to installing the full suite of instruments at each measurement site. These instruments would be installed at some oblique angle to the axis of the shaft so that horizontal convergence magnitudes and rates can be calculated.

The required accuracy and precision of instrumentation used to collect in situ data in a monitoring program depends largely on the intended application and expected range of results (Wilder et al., 1982). Instrumentation required for activities related to model validation must have a high degree of accuracy and precision over a relatively short operational period.

Table 3.1.1-2: Technical Procedures Required For The Shaft Convergence Experiment

- Procedure for Diamond Drilling Holes for Instrumentation
- Procedure for Overcoring for Stress measurements
- Procedure for Biaxial Stress Measurement for Overcore Testing
- Procedure for the Installation and Operation of Rod Extensometers
- Procedure for the Installation And Operation of MPBXs
- Procedure for the Installation and Operation of HPCs
- Procedure for the Installation and Operation of Borehole Deformation Gauges
- Procedure for Borehole Inspection Using a Borescope
- Procedure for Definition of Joint Properties and Geometries
- Procedure for Percussion Drilling Holes for Instrumentation
- Procedure for Monitoring Pressure Controls
- Procedure for Data Acquisition System Monitoring

Conversely, instrumentation intended for long-term monitoring applications will generally sacrifice some degree of accuracy and precision to ensure reliability over the time intervals required. In either case, the instrumentation employed must be compatible with the intended application to help ensure that the experimental objectives are achieved.

The range of results and the equipment required for the Shaft Convergence Experiment are summarized in Sections 3.1.3 and 3.1.4, respectively. The accuracy and precision of each of the instruments utilized in this experiment is summarized below.

The principal factors that influence the accuracy of MPBXs are: (1) anchor slippage; (2) thermal expansion of the components; (3) friction acting on the rods; and (4) displacement transducer performance. Wilder et al. (1982) discuss the effect of these factors on the measurements obtained with MPBXs. Three types of six anchor MPBXs are being considered for installation in the Shaft Convergence Experiment. The response of each MPBX type in welded tuff is currently being evaluated based on results from G-Tunnel welded tuff (Zimmerman et al., 1987; 1988). The results of these evaluations will be used to select the most appropriate MPBX and associated anchor spacing. An IRAD Model 4500 MPBX with groutable anchors and Invar rods may be used at several measurement stations. This type of MPBX uses a depth micrometer and sonic probes to measure the rod travel distance. The second type of MPBX that may be used is the Terrametrics Model 293 which also has groutable anchors and Invar rods but uses a linear variable displacement transducer (LVDT) to measure displacement. A third type of MPBX, the Roctest BOF-Ex has mechanical anchors and uses an LVDT to measure displacement. A principal advantage of the Roctest MPBX is that the components of the system can be removed, recalibrated and replaced within a few hours if the MPBX begins to malfunction. The sensitivity of all three units is about 0.025 mm.

Anchor stability is crucial to the accuracy of the MPBX system. Tests performed in G-Tunnel (Zimmerman et al., 1987; 1988) have demonstrated that grouted anchors located in the vicinity of blasting operations have remained stable for periods of greater than 200 days. However, in areas of severely jointed rock the amount of grout that is used must be closely monitored to avoid having the grout enter the fractures and altering the deformation characteristics of the rock mass.

The accuracy of the MPBX can be greatly influenced by the thermal expansion of the various components, in particular the Invar rods, at temperatures in excess of 200° C. The ambient temperature within the Exploratory Shaft Facility will be less than 30 °C during the Excavation Investigations Study, with local variations of only a few degrees centigrade during the experiments. These temperatures are well below the temperature range where the non-linear thermal expansion coefficient of Invar rods becomes a major concern.

Friction acting on the rods, often manifested by stick-slip behavior resulting in pronounced jumps in displacement data, influences the accuracy of the MPBX data. Proper alignment of the rods with the head assembly and appropriate installation procedures generally alleviates the stick-slip problem and minimizes its impact.

An IRAD Model RFR rod extensometer will probably be used to obtain shaft convergence measurements. The extensometer uses a sonic probe as the sensing unit with a sensitivity of ± 0.025 mm. Measurements will be obtained between anchors mounted in the shaft at each station. The accuracy of the rod extensometer measurements can be greatly influenced by the instability of the anchors during the blasting operations that occur after anchor installation, temperature effects, and variations that result from subtle changes in operational procedures that may occur with different operators. The effects of each of these factors on the accuracy and precision of the rod extensometer measurements will be greatly reduced when the technical procedures described in Section 3.1.1 are utilized.

The accuracy of the USBM borehole deformation gauge is dependent on a number of factors including gauge sensitivity as a function of temperature, bridge input and output voltage, bridge offset as a function of temperature and gauge thermal expansion coefficient (Wilder et al., 1982). Laboratory testing in engineered materials have yielded highly accurate deformation measurements of 0.002 mm with a sensitivity of ± 0.001 mm. Gauge sensitivity and bridge offset are subject to long-term drift which is greatly influenced by localized test conditions at the transducer. The magnitude of drift is not predictable and must be controlled by periodic recalibration.

Stress changes are primarily calculated from deformation data; therefore, accuracy is dependent on the knowledge of rock properties (Young's modulus, Poisson's ratio, and thermal expansion coefficient) and the degree to which the rock mass behaves as a linear elastic and isotropic medium. Errors in calculating stress changes are directly proportional to the errors involved in selecting the appropriate rock modulus, where the scale of changing rock characteristics (e.g. fracture spacing and orientation) are often the most important variable influencing the magnitude of the stress change. Thus, a thorough understanding of the geology at each measurement station, using borehole surveys in combination with data obtained from Study 8.3.1.4.2.1: Characterization of the Vertical and Lateral Distribution of Stratigraphic Units Within the Site Area, is essential to minimize the errors in the stresses calculated with the borehole deformation gauge.

Terrametrics/Glotzl Concrete Stress Cells, Model B 10/20 or a comparable unit with similar characteristics will be used to monitor the shaft liner stress. The reported accuracy of the hydraulic pressure cell is 10 kPa with a maximum stress recording capability of 30 MPa. Variations in temperature can inadvertently influence the stress measurements, although within the expected ambient temperature range, these errors should be within the range of accuracy of the HPC. Other errors may result from the orientation of the HPC relative to the liner or an inappropriate matching of the HPC with the material stiffness of the liner. Testing in G-Tunnel (Zimmerman et al., 1987; 1988) is presently evaluating these and other potential sources of error associated with the HPCs.

3.1.3 Range of Expected Results

The expected range of values for each of the activities performed in the Shaft Convergence Experiment (Table 3.1.3-1) have been estimated on the basis of data obtained in the welded tuff composing the Grouse Canyon Member located in G-Tunnel (Zimmerman and Finley, 1987) and laboratory data obtained form the welded tuff composing the Topopah Spring Member at Yucca Mountain (Price et al., 1985). The range and magnitude of the results are intended to satisfy the requirements for accuracy and precision outlined in Section 3.1.2 of this Study Plan.

3.1.4 Equipment and Design Requirements

Requirements for the Shaft Convergence Experiment are outlined in the Exploratory Shaft Facility Subsystems Design Requirements Document (1987) and will be documented in the Shaft Convergence Experimental Procedure Document. Instrumentation, equipment, and material requirements are summarized in Table 3.1.4-1.

3.1.5 Analyses of Field Measurements

3.1.5.1 Horizontal Stress Measurements

The analysis of overcoring measurements will be performed using the equations developed by Panek (1966). In this analysis, the three borehole diameter measurements provide a data set that can be used for the solution of three simultaneous equations, if the vertical stress is assumed to be caused by lithostatic loading. This assumption is supported by available data from Yucca Mountain (Stock et al., 1985) and should be valid where the vertical stress has not been altered by excavation.

Table 3.1.3-1: Expected Range Of Results For Activities Performed During The Shaft Convergence Experiment

Activity	Parameter Measured	Estimated Range of Value
Horizontal Stress	In Situ Horizontal Stress	< 10 MPa
Estimate of Stress Altered Region	MPBX Anchor Displacement	0-10 mm
Convergence Magnitude	Displacement	0-10 mm
Convergence Rate	Displacement/Time	0-2 mm/year
Liner Contact Pressure	Liner Stress	< 15 MPa

Table 3.1.4-1: Summary of Equipment, Instrumentation And Materials Required For The Shaft Convergence Experiment

Item	Description
Rod Extensometer	Rated Sensitivity of ± 0.025 mm
Multiple Point Borehole Extensometer	Rated Sensitivity of ± 0.025 mm
Borehole Deformation Gauge	Rated Sensitivity of ± 0.001 mm
Hydraulic Pressure Cell	Rated Sensitivity of 10 kPa

3.1.5.2 Estimate of the Stress Altered Region

The extent of the stress altered region will be estimated using the relative displacements measured between each of the six MPBX anchors spaced at nominal intervals of 1, 2, 3, 4, 5, and 15 m from the collar, the cumulative displacement of all six anchors, and the total convergence measured between the three sets of MPBX collars and convergence anchors. The radial distance at which the relative displacements between anchors approaches zero will be used to approximate the limits of the stress altered region. An evaluation of different MPBX anchor types will be completed in G-Tunnel welded tuff (Zimmerman et al., 1987; 1988) to determine if a larger number of anchors or more closely spaced anchors can be used. The difference between the cumulative displacement measured with the MPBX anchors and the total shaft convergence measured between sets of convergence anchors or MPBX collars will also be used to estimate the extent of this region. The difference between the convergence magnitudes calculated using these techniques can be ascribed to at least three factors: (1) convergence of the rock mass occurring beyond the last anchor installed 15 m away from the rib; (2) displacement of the blast damaged zone which may not be measured with the MPBX anchors; and (3) differential movement associated with fractures or an asymmetrical rock mass response on either side of the shaft. Minimal differences between these values will significantly increase the level of confidence in the estimate of the extent of the stress altered region.

3.1.5.3 Shaft Liner Analyses

The overall liner-rock analyses provide data that will be used by the designers to assess the adequacies of the liner design as the liner responds to the potential relaxation in the surrounding rock. Pressure measurements obtained within the liner can be extrapolated to predict equivalent stresses at the surface of the liner by using elastic theory as it applies to thick-walled cylinders (Timoshenko and Goodier, 1951). The displacements at the liner-rock interface should prove to be compatible with the measured stress changes as long as the liner acts as a linear elastic structural unit and the liner and rock are well-bonded.

3.1.6 Representativeness of Results

The measurement stations selected for the Shaft Convergence Experiment are intended to assess the variations in geomechanical characteristics that are likely to be encountered in vertical profile within Yucca Mountain. Specifically, measurement stations have been selected to sample the high lithophysae (15-20 %) interval of the Topopah Spring Member and the densely welded tuff interval, containing less than 10 % lithophysae, to assess variations in horizontal stress, convergence rates and displacement magnitudes, variations in liner stress imposed by differing geology, and the extent of the stress altered region. Variations in the horizontal stress state will be evaluated for differing geologic horizons that compose the reference geological and geomechanical units within the ESF. These data will be combined with stress data obtained in the characterization of the Site Ambient Stress Conditions Study to evaluate the effects of geologic variations at a specific depth with the changes in stress attributed to varying depths representative of the Yucca Mountain repository location. Fracture characteristics are likely to vary between geologic horizons and with changes in the lithophysae content. The data obtained should be representative of the fracture conditions encountered elsewhere in the Exploratory Shaft Facility but may differ markedly from those areas where faulting is pervasive.

3.1.7 Performance Goals and Confidence Levels

The performance allocation process has identified the performance goals and confidence levels required to resolve the key issues addressed by the Excavation Investigations Study experiments (Information Needs 1.11, 4.2, 4.4 and Investigation 8.3.1.15). These goals and confidence levels are summarized in Tables 1.2.1.1 and 8.3.1.15.1 of the SCP.

As discussed in Section 8.3.1.15 of the SCP, the required confidence levels for geomechanical parameters requires a minimum number of measured samples for each measured property. The minimum number of samples required to satisfy the confidence level is always larger than the number of in situ tests that will be conducted. Thus, the data obtained from the in situ experiments will serve as guideline values that will be used to examine the validity of extrapolating the laboratory derived values to in situ conditions. If these extrapolations do not appear valid then the performance goals will need to be re-evaluated and an approach that relies more heavily on either field or laboratory data will possibly be adopted.

3.2 Demonstration Breakout Rooms Experiment

The Demonstration Breakout Rooms (DBRs) Experiment will be conducted in repository-size rooms located at two different intervals within the Topopah Spring Member that have significantly different lithophysae contents and fracture densities. The configuration of this experiment may be changed in response to modifications in the design of the Exploratory Shaft Facility. The rooms will be connected to the Exploratory Shaft at depths of about 158 m and 311 m, corresponding to the upper breakout level and main test level, respectively. The orientation of the DBRs will coincide with the orientation established for the underground facility (MacDougall et al., 1987) with some possible minor modifications depending on the dominant fracture orientation and in situ stress conditions at each DBR location. Each DBR will be repository-size, with the opening dimension comparable to the widest opening planned for the underground facility, in an attempt to increase the measurable displacements around the perimeter of the underground opening. These ratios are comparable for both the horizontal and vertical emplacement options (MacDougall et al., 1987). The length of each DBR will be six times the width. Measurements obtained in the midsection of these rooms are not expected to be influenced by end effects resulting from the Exploratory Shaft opening or the drift face (Petney, 1986) and should be representative of conditions encountered in the underground facility. Drift convergence will be evaluated during the excavation and stabilization process to delineate differences in the rock mass response as a result of varying geological characteristics. The repository-size drifts will also be used for other in situ experiments (e.g., Overcore Stress, Anelastic Strain Recovery, Plate Loading, Mechanical Strength, and Laboratory Study of Intact Rocks) that relate directly to the design of the underground facility.

Eleven measurement stations, beginning 4.4 m from the beginning of the drift, will be located at 2.4 m intervals in each DBR location (Figure 3.2-1). Each of these stations will be instrumented with drift convergence anchors and rock bolts with attached load cells. At five measurement stations located 6.8, 11.6, 16.4, 21.2, and 26.0 m from the beginning of the drift (Figure 3.2-1), six MPBXs will be installed. Each MPBX will contain at least five anchors located at nominal 1 m intervals from the perimeter of the opening. A sixth reference anchor will be located a minimum of 15 m from the perimeter of the opening in rock that has not been altered by the excavation process.

During the mining operation rock bolts will be installed in each of the rooms using a pattern designed to maintain stability. The ground support requirements will be determined on the basis of experience developed from mining other welded tuff locations using both analytical and empirical techniques described in the Site Characterization Plan-Conceptual Design

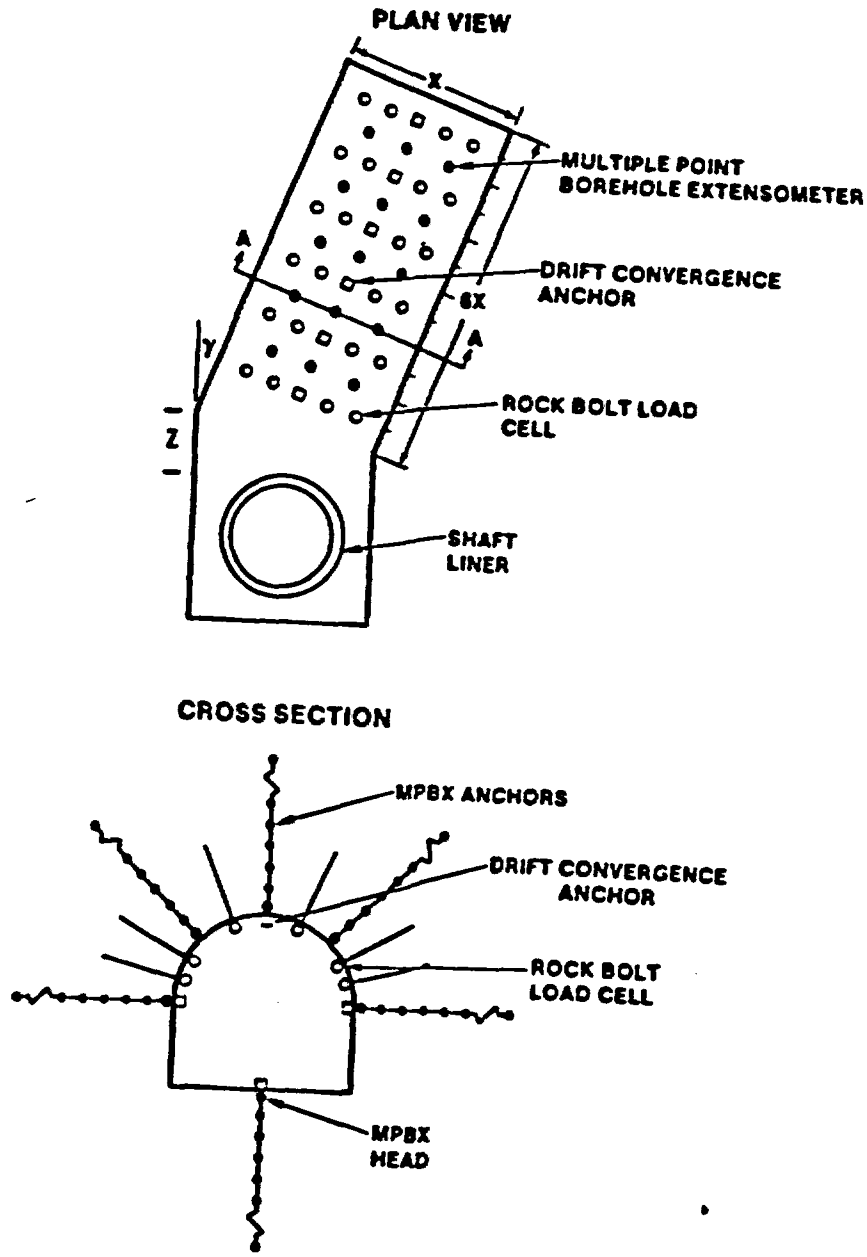

Figure 3.2-1: Plan View Schematic Of Instrumentation Locations For The Demonstration Breakout Rooms Experiment (Top). The Orientation Of The Rooms (γ) Will Coincide With The Orientation Of The Underground Facility. The Offset Distance (Z) Between The Exploratory Shaft And The Start Of Excavation Will Be Determined Based On Construction Needs. Schematic Of Instrumentation Locations Planned At Each Of the 5 MPBX Measurement Stations (Section A-A; Bottom).

Report (MacDougall et al., 1987). At each measurement station, the appropriate instrumentation will be installed and measurements will be initiated to determine displacement magnitudes, variations in support loading, and the extent of the stress altered region. Drift convergence measurements will be made using rod extensometers at each station while the MPBX measurements are performed at the stations located at 6.8, 11.6, 16.4, 21.2, and 26.0 m. Estimates of the extent of the stress altered region will be made using the MPBX data.

Excavation efficiency will be evaluated qualitatively during the construction of the rooms. Evaluations will include documenting the controlled blasting procedure employed (i.e., charge density and configuration, delay sequence, hole spacing, etc.) and an assessment of the advance rates, amount and size of loosened blocks and the amount of overbreak and underbreak evident after each round. A detailed evaluation of excavation efficiency that includes varying the excavation techniques employed will be completed during the In Situ Design Verification Study (8.3.1.15.1.8). The rock bolt load cell, MPBX and rod extensometer data obtained at the measurement stations will also be used to assess the excavation efficiency. Variations in the forces and displacements associated with the underground opening will be monitored to evaluate the degree of uniformity in the rock mass at a single station and with respect to the entire length of the Demonstration Breakout Rooms.

3.2.1 Quality Assurance Requirements and Technical Procedures

The quality assurance level assignment for each activity is summarized from the Exploratory Shaft Geomechanical Test Quality Assurance Level Assignments (QALA), NNWSI Element 1.2.6.9.2.3.S (Table 3.2.1-1). The drift convergence magnitude, drift convergence rate, estimate of the stress altered region, and excavation efficiency activities are all Quality Assurance Level II because the activities only have a major impact on the non-radiological structural reliability of the engineered system.

Table 3.2.1-1: Quality Assurance Level Assignments For Each Activity Planned In The Demonstration Breakout Rooms Experiment

Activity	Quality Assurance Level Assignment
Drift Convergence Magnitude Measurements	II
Drift Convergence Rate Measurements	II
Estimate of Stress Altered Region	II
Excavation Efficiency Estimate	II

All work will be performed in accordance with the Sandia National Laboratories Quality Assurance Program Plan (1986).

The Demonstration Breakout Rooms Experimental Procedure will describe the operational and technical procedures required to fulfill the experiment objectives. Technical procedures for each of the methods employed during the Demonstration Breakout Rooms Experiment (Table 3.2.1-2) will be completed at least six months prior to initiating the excavation of the DBRs.

3.2.2 Accuracy and Precision

The accuracy and precision of the Demonstration Breakout Rooms data is subject to the same constraints as the data obtained in the other Excavation Investigations Study experiments. The range of results and equipment required for the Demonstration Breakout Rooms Experiment is summarized in Study Plan Sections 3.2.3 and 3.2.4, respectively. The accuracy and precision of the MPBXs and rod extensometers in this experiment will be contingent on the same factors as in the Shaft Convergence Experiment (Study Plan Section 3.1.2) and a description will not be repeated here.

Rock bolt load cells that use strain gauges as the sensing units (e.g., Terrametrics Model PC-60) will be used to monitor changes in rock bolt tension that occurs after installation. The load cells will be attached to mild steel rock bolts using the technical procedures listed in Study Plan Section 3.2.1. The load cells have a capacity of 535 KN and a sensitivity of ± 267 N. Long-term monitoring of rock bolt tension requires that the load cells be capable of withstanding the effects of near-by blasting and be sealed to prevent water and/or dust from entering the housing of the load cell. Experience in G-Tunnel welded tuffs (Zimmerman et al., 1988) indicate the long-term stability for the Terrametrics load cell exceeds periods of greater than 200 days. The strain gage circuits should be temperature compensated to minimize the effects of ambient temperature changes on the measured strains. Resistance

Table 3.2.1-2: Technical Procedures Required For The Demonstration Breakout Rooms Experiment

- Procedure for Diamond Drilling Holes for Instrumentation
- Procedure for Percussion Drilling Holes for Instrumentation
- Procedure for the Installation and Operation of MPBXs
- Procedure for the Installation and Operation of Rock Bolt Load Cells
- Procedure for Borehole Inspection Using a Borescope
- Procedure for the Definition of Joint Properties and Geometries
- Procedure for Rock Bolt Installation
- Procedure for Data Acquisition Monitoring
- Procedure for the Installation and Operation of Rod Extensometers

changes due to varying cable lengths and connections can also influence the accuracy of the load cell measurements.

3.2.3 Range of Expected Results

The expected range of values for each of the activities performed in the Demonstration Breakout Rooms Experiment (Table 3.2.3-1) have been estimated on the basis of data obtained in the welded tuff composing the Grouse Canyon Member located in G-Tunnel (Zimmerman and Finley, 1987).

3.2.4 Equipment and Design Requirements

Requirements for the Demonstration Breakout Rooms Experiment are outlined in the Exploratory Shaft Facility Subsystems Design Requirements Document (1987) and will be documented in the Demonstration Breakout Rooms Experimental Procedure Document. Requirements for instrumentation, equipment, and material requirements are summarized in Table 3.2.4-1.

3.2.5 Analyses of Field Measurements

3.2.5.1 Drift Convergence Measurements

Drift convergence rates and displacement magnitudes will be determined at each measurement station using data obtained after each blast round. A cumulative record that will contain plots of displacement as a function of time, face distance from the measurement station, and distance to the last station for rock bolt placement will be used to calculate and interpret drift convergence rates and displacement magnitudes.

Drift convergence magnitudes will be determined using data obtained from the rod extensometers and the head movements of the MPBXs relative to the deepest anchor at 15 m. These measurements should compare, although local differences in rock characteristics (i.e. fracture density and orientation, lithophysae content, etc.) may result in measurable differences.

Table 3.2.3-1: Expected Range Of Results For Activities Performed During The Demonstration Breakout Rooms Experiment

Activity	Parameter Measured	Estimated Range Of Value
Drift Convergence Magnitude	Displacement	0-10 mm
Drift Convergence Rate	Displacement Rate	0-2 mm/year
Estimate of Stress Altered Region	MPBX Anchor Displacement	0-5 mm

Table 3.2.4-1: Summary Of Equipment, Instrumentation, And Materials Required For The Demonstration Breakout Rooms Experiment

Item	Description
Rock Bolt Load Cell	Rated sensitivity to ± 267 N
Multiple Point Borehole Extensometer	Rated sensitivity to ± 0.025 mm
Rod Extensometer	Rated sensitivity to ± 0.025 mm

3.2.5.2 Estimate of the Stress Altered Region

An estimate of the stress altered region will be performed using the displacement data obtained with the MPBXs and the technique discussed by Brown (1981) and summarized in Study Plan Section 3.1.5.3. The limit of the stress altered region occurs where the change in displacements between consecutive anchors approaches zero.

Data from the load cells will also be used to augment the estimate of the stress altered region based on MPBX data. Several factors influence the force changes measured by the load cells including fracture characteristics and the time dependent rock mass relaxation and stress changes that occur during excavation. The uniformity of the rock mass mechanical response to these factors will be used to assess the variability in rock mass characteristics that can also influence the extent of the stress altered region.

3.2.5.3 Excavation Efficiency Estimate

Evaluation of the excavation efficiency will focus on documenting the techniques employed for excavation (e.g., drilling patterns, hole depths, charge density, etc.), and the results of these techniques (e.g., advance rate, amount of overbreak or underbreak, etc.) in varying geologic conditions. The efficiency of the construction process is required for budgetary and scheduling purposes.

Rock bolt load cell, MPBX and rod extensometer data obtained at the measurement stations within each DBR will also be used to assess the excavation efficiency. Variations in the forces and displacements associated with the underground opening will be monitored to evaluate the degree of uniformity in the rock mass at a single station and with respect to the entire length of the DBR. The variations measured with the rock bolt load cells will be compared with localized changes in the geologic character (i.e., fracture density and orientation, lithophysae content, etc.) and the effects of mining, evident visually, to provide a preliminary assessment of excavation efficiency. A detailed evaluation of excavation efficiency will be performed during the In Situ Design Verification Study (8.3.1.15.1.8).

3.2.6 Representativeness of Results

The activities performed during the Demonstration Breakout Rooms Experiment are designed to evaluate the influence of varying geologic and geomechanical characteristics on the design proposed for repository-size drifts. The lithophysae content encountered at the two locations is expected to bound the range of lithophysae that is representative of the conditions at Yucca Mountain in general (Nimick et al., 1988). The variation in fracture density is also expected to be representative of conditions found in Yucca Mountain except in those areas associated with well-developed faulting. The in situ stress conditions at the upper breakout level will not be representative of the stress conditions at the main test level. This difference results primarily from the difference in depth associated with these two levels. Ground support requirements for both drifts will be developed using the same requirements planned for designing the ground support for most of the repository.

3.2.7 Performance Goals and Confidence Levels

The locations of the Demonstration Breakout Rooms within the Exploratory Shaft Facility are intended to bound the site-specific geologic and geomechanical characteristics that should be encountered in the underground facility. Construction in these variable conditions will be used to demonstrate that available technology and planned ground support systems are adequate for the expected site-specific conditions.

The performance allocation process has identified the performance goals and confidence levels required to resolve the key issues addressed by the Excavation Investigations Study experiments (Information Needs 1.11, 4.2, 4.4, and Investigation 8.3.1.15). These goals and objectives are summarized in SCP Tables 1.2.1.2 and 8.3.1.15.1.

As discussed in SCP Section 8.3.1.15, the required confidence levels for geomechanical parameters requires a minimum number of measured values that vary with each property if the properties are sampled at random. The locations of the DBRs have been chosen to provide the range of lithophysae that are expected to be encountered in the Exploratory Shaft Facility and fracture density and spacing that is expected to be representative of conditions prevalent in Yucca Mountain except in areas with well-developed faulting. By carefully selecting the DBR locations using borehale data that will serve as an index to critical parameters and observations during shaft construction, the DBR results should bound the conditions expected to influence performance and help to reduce the number of large-scale tests required to achieve the needed confidence.

3.3 Sequential Drift Mining Experiment

The Sequential Drift Mining Experiment will provide an additional suite of data for model validation. Measurements performed in this experiment will be used to better define the extent of the stress altered region, composed of the blast damaged zone and the stress redistribution zone. This experiment will be performed in and around two drifts located at the main test level within the Exploratory Shaft Facility. The experimental design is preliminary and will be optimized using pre-test analyses, experience gained in G-Tunnel, and experience from previous Excavation Investigations Study experiments to facilitate the analyses required for model validation. Measurements will be performed to characterize the rock mass prior to and after the excavation of two drifts using controlled blasting techniques to evaluate the effects of the excavation process on the rock mass and the radial extent of these effects away from the excavated opening. A third drift, oriented either parallel or orthogonal to the other two drifts, may be added to this experiment. This drift will be used to obtain additional geologic characterization data, provide additional data on the rock mass response to excavation, and to obtain additional measurements for developing a data base to exercise the three-dimensional components of the rock-mass constitutive models.

The validation of the constitutive models are a necessary step in predicting repository behavior during the preclosure phase of the repository. The emphasis in the Sequential Drift Mining Experiment is to relate the predictions of the models to the measurements obtained during and after excavation. This information will be used to develop design guidelines for the underground facility that can be used for the underground conditions encountered during the excavation process.

A provisional experimental plan for the Sequential Drift Mining Experiment that emphasizes the use of two drifts is summarized for discussion purposes only. This plan will change, possibly significantly, as data from the other Excavation Investigations Study experiments become available. Some planned measurements are intended to form a data base for comparison with calculations using the models in three-dimensions, although the exact nature of these measurements will not be determined until the requirements for the models and the plans for the In Situ Thermomechanical Study are finalized.

The Sequential Drift Mining Experiment will begin by excavating a drift (Drift A; Figure 3.3-1) of appropriate size to adequately instrument the rock in the region where a second drift (Drift B) of repository size will be excavated. The thickness of the pillar separating these drifts may be varied to increase the induced stress levels and measureable displacements in Drift B. A series of holes will be diamond drilled into the rib of Drift A to characterize the rock mass associated with

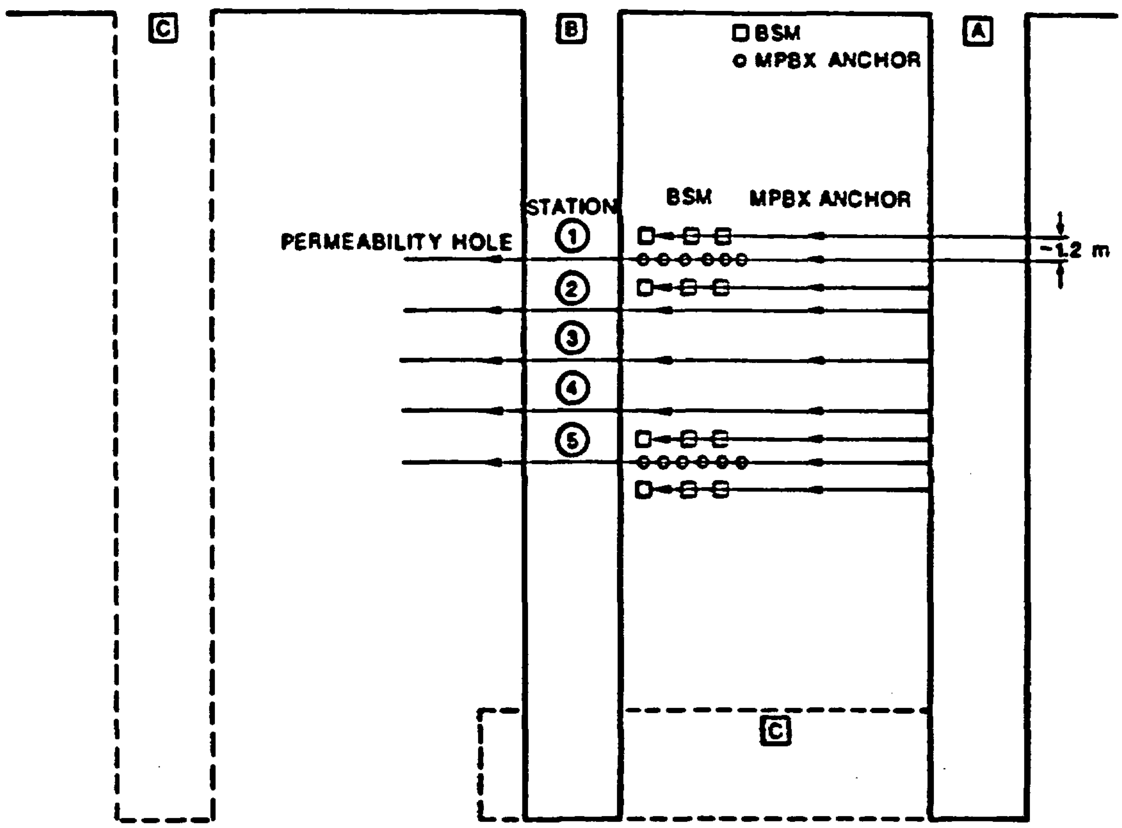

Figure 3.3-1: Plan View Showing Provisional Layout Of Drifts A And B And Approximate Locations Of Instrumentation Boreholes. A Third Drift (Drift C) May Be Excavated Either Parallel Or Orthogonal To Drifts A And B To Obtain Additional Geological Characterization Data, To Provide Additional Data On The Rock Mass Response To Excavation And To Establish A Data Set For Exercising The Three-Dimensional Components Of The Rock-Mass Constitutive Models. Dimensions Are Likely To Change As The Experimental Plan Becomes Formalized.

Drift B prior to and after excavation. The first drilling station will be located approximately three drift diameters from the start of Drift A, with subsequent holes drilled at nominal 1.2 m or 2.4 m intervals. These holes will be used to characterize the rock mass to establish a reference data base for future use and to develop a three-dimensional understanding of the geology in the region around Drift B.

A number of different types of measurements will be made using the instrumentation installed in holes drilled in the rib of Drift A (Figure 3.3-2). Air and water borehole permeability measurements will be performed in each of the boreholes located in the rib of Drift B before, during, and after mining Drift B. Air permeability measurements will be completed to provide data to perform a preliminary evaluation of any correlation between air and water permeability measurements from the same location. At each selected interval the straddle packers will be set and steady state pressure injections will be made at several different pressure settings to establish a hydraulic quotient. This quotient describes the average ratio of pressure to flow rate for each interval tested. This process will be repeated at a number of intervals within each borehole to establish an average hydraulic quotient prior to mining Drift B. This process will be repeated during and after the mining of Drift B in each of the boreholes that have not been instrumented and the results compared to determine the effects of excavation on permeability. Data obtained in the other stations will be used to locate and map fracture patterns and, in conjunction with borescope measurements, will be used to develop a geologic fracture model for the pillar located between the measurement stations (Figure 3.3-1).

Cross borehole ultrasonic measurements will be performed using a 30-50 kHz transceiver capable of transmitting and receiving compressional waves over a 1-m interval before and after mining in the boreholes that will be used to establish the hydraulic quotient. These measurements will be obtained in the

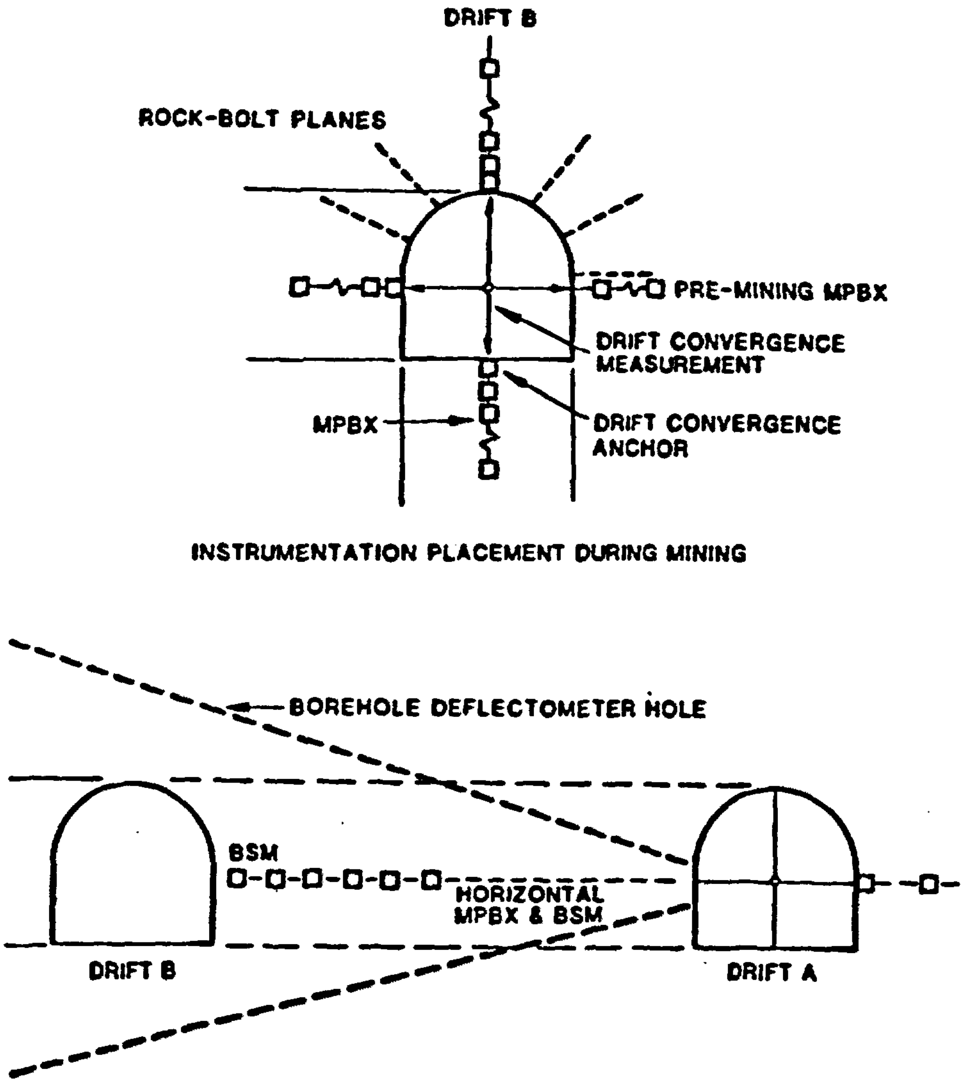

Figure 3.3-2: Schematic Of Instrumentation Planned During The Mining Process For Each Measurement Station In Drift B (Top). Cross-Drift Instrumentation Arrangements Between Drifts A And B (Bottom). Dimensions Are Likely To Change As The Experimental Plan Becomes Formalized.

stress altered region associated with Drift B. The measurements will be repeated with the transmitter and receiver interchanged to establish directional variations in the stress altered region that may be related to geology.

Borehole deflectometer measurements will be obtained along the full-length of two inclined boreholes. Small borehole angle deviations will be measured before and after the mining of Drift B to establish small-scale angle changes as a result of dilation of the rock mass into the opening of Drift B. Continuous monitoring during the mining of Drift B will be performed using MPBXs and borehole stressmeters installed between Drifts A and B and rod extensometer measurements obtained between drift convergence anchors. MPBXs will be installed in the pillar between the drifts at each measurement station prior to mining Drift B. The end anchors of each MPBX will be located about 0.5 m from the proposed Drift B rib location with each successive anchor installed at nominal 1 m intervals. The exact anchor locations will depend on the geology encountered in the underground facility and on the ability to control the radial extent of blast damage which may damage the anchors. These anchors will be used to measure the displacement of the rib into the cavity of Drift B.

Four of the horizontal boreholes originating in Drift A will be used for the installation of borehole stressmeters with strain gauge sensors. Each hole will be located so that one of the stressmeters is located about 1 m from the proposed Drift B rib location with the other two located in the pillar between the drifts. The stressmeters will monitor the stress redistribution effects and the stress changes related to mining. The uniformity of the stress changes will be assessed along individual boreholes using the three borehole stressmeters and within the pillar between drifts using the data obtained from each of the boreholes.

Several measurement stations will be established in Drift B to monitor drift convergence while excavation proceeds. Three MPBXs will be installed at two or three measurement stations

(Figure 3.3-2) to augment the rod extensometer measurements that will be obtained manually at each of the stations in Drift B. After the excavation of Drift B is complete the measurements obtained in Drift A prior to mining will be repeated for comparison.

3.3.1 Quality Assurance Requirements and Technical Procedures

The quality assurance level assignment for each activity is summarized from the Exploratory Shaft Geomechanical Test Quality Assurance Level Assignments (QALA), NNWSI Element 1.2.6.9.2.3.S (Table 3.3.1-1). All activities performed during the Sequential Drift Mining Experiment will be performed at a Quality Assurance Level I. All work will be performed in accordance with the Sandia National Laboratories Quality Assurance Program Plan (1986).

The Sequential Drift Mining Experimental Procedure will describe the operational and technical procedures required to fulfill the experiment objectives. Technical procedures for each of the methods employed in the Sequential Drift Mining Experiment (Table 3.3.1-2) will be completed at least six months prior to the start of excavating Drifts A and B.

3.3.2 Accuracy and Precision

The range of results and the equipment required for the Sequential Drift Mining Experiment is summarized in Sections 3.3.3 and 3.3.4, respectively. The accuracy and precision of the MPBXs and the rod extensometers have been discussed in Section 3.1.2. The accuracy and precision of these instruments will be dependent on the same sources of error as in the applications discussed earlier and will not be reiterated.

Rigid inclusion borehole stressmeters with a strain gauge sensor developed by Sandia National Laboratories (Cook and Ames, 1979) will probably be used to monitor borehole stress changes. These units have a sensitivity of $\pm$ 130 kPa. The calibration of

Table 3.3.1-1: Quality Assurance Level Assignments For Each Activity Planned In The Sequential Drift Mining Experiment

Activity	Quality Assurance Level Assignment
Drift Convergence Magnitude Measurements	I
Drift Convergence Rate Measurements	I
Estimate of Stress Altered Region	I
Excavation Efficiency Estimate	I
Water Permeability Measurements	I

Table 3.3.1-2: Technical Procedures Required For The Sequential Drift Mining Experiment

- Procedure for Diamond Drilling for Instrumentation
- Procedure for Percussion Drilling for Instrumentation
- Procedure for the Installation and Operation of Rod Extensometers
- Procedure for the Installation and Operation of Rock Bolt Load Cells
- Procedure for the Installation and Operation of Borehole Deflectometers
- Procedure for the Installation and Operation of Borehole Stress Meters
- Procedure for the Installation and Operation of Water Permeability Equipment
- Procedure for Borehole Inspection Using a Borescope
- Procedure for the Definition of Joint Properties and Geometries
- Procedure for Rock Bolt Installation
- Procedure for Data Acquisition System Monitoring
- Procedure for the Installation and Operation of MPBXs

the rigid inclusion stressmeters is dependent on several factors including the elastic properties of the media, the platen contact area, the borehole size, loading conditions, temperature, and the pre-stress level during installation (Wilder et al., 1982). Each of these factors can contribute to a significant amount of scatter in results performed at the same interval. Tests in G-Tunnel (Zimmerman et al., 1988) will be used to analyze the magnitude of the errors that can be anticipated for jointed welded tuff.

Borehole deflectometers will be used to measure angular deviations of the borehole axis which can be summed over a period of time to provide displacement information. Precision of the deflectometers is expected to be on the order of 2 to 4 arc seconds and the resolution is 0.75 arc seconds. Temperature fluctuations, generally greater than 15 °C and zero drift can both have a significant effect on the accuracy of the angular deviations measured and subsequent displacements. The accuracy of the inclinometer is generally constrained by the orientation of the instrument at the same point in the casing.

Straddle packers connected to a flow meter and pressure gage will be used for the fracture permeability testing. The sensitivity of the flow meter and the water flow range will be determined using G-Tunnel Mining Evaluation test results (Zimmerman et al., 1988). Measurements will be obtained under steady state flow conditions at up to five pressure-flow rate steps. A detailed description of the fracture characteristics over the interval tested, performed before and after the mining of Drift B, is required to minimize the error induced by variable geology and possibly increased flow rates. The packers must be properly seated within the borehole to minimize leakage around the packer over the time interval required for the test. Experience gained from the G-Tunnel Mining Evaluation test (Zimmerman et al., 1988) will be used to develop the technical procedures that are required to perform the permeability measurements in welded tuffs with minimal error.

3.3.3 Range of Expected Results

The expected range of values for each of the activities performed during the Sequential Drift Mining Experiment are estimated on the basis of data obtained in the welded tuff Grouse Canyon Member located in G-Tunnel (Table 3.3.3-1; Zimmerman and Finley, 1987).

3.3.4 Equipment and Design Requirements

Construction and experiment requirements for the Sequential Drift Mining Experiment are outlined in the Exploratory Shaft Facility Subsystems Design Requirement Document (1987) and will be documented in the Sequential Drift Mining Experimental Procedures Document. The instrumentation requirements are summarized in Table 3.3.4-1.

3.3.5 Analysis of Field Measurements

3.3.5.1 Drift Convergence Measurements

The primary data used for the validation of the rock-mass constitutive models are the drift displacement magnitude data. Displacement data will be recorded at several drift convergence stations located in Drift B until excavation is completed. These data will be analysed using the methods previously described in Study Plan Section 3.2. The uniformity of the vertical drift convergence measurements will be analyzed and, if reasonable agreement exists between the data obtained at each station, representative values will be determined. The representative values determined for the drift displacement magnitude data will be used as the basis for comparison of the predicted convergence values with the measured values. If there is not congruence of the displacement data between stations, additional geologic characterization studies will be performed to establish

Table 3.3.3-1: Expected Range Of Results For Activities Performed During The Sequential Drift Mining Experiment

Activity	Parameter Measured	Estimated Range of Value
Drift Convergence Magnitude	Displacement	0-10 mm
Drift Convergence Rate	Displacement/ Time	0-2 mm/year
Rib Stress Change	Stress Change	< 15 MPa
Estimate of Stress Altered Region	MPBX Displacements	0-5 mm
	Compressional Velocity	2-5 km/s
	Borehole Angle Change	< 0.2^{o}
Permeability	Flow Rate	< 1260 cm^3/s
	Flow Pressure	< 1.4 MPa

Table 3.3.4-1: Summary Of Equipment, Instrumentation, And Materials Required For The Sequential Drift Mining Experiment

Item	Description
MPBX	Rated sensitivity to ± 0.025 mm
Borehole Stressmeter	Rated sensitivity to ± 130 kPa
Rod Extensometer	Rated sensitivity to ± 0.025 mm
Borehole Deflectometer	Rated sensitivity to ± 2 arc seconds
Fracture Permeability Instrumentation	Rated sensitivity to ± 1.0 cm^3/s
Ultrasonics	Rated sensitivity to ± 50 m/s

if the lack of uniformity is a result of the geologic structure, the accuracy of convergence measurements or a lack of understanding inherent to the models predicting displacements.

The validation process is documented in Section 8.3.2.1.4.3 of the Site Characterization Plan. The process consists of a series of steps that include: (1) analysis of the experiment design to ensure that the experiment addresses the appropriate phenomena; (2) collection of site specific data and material properties for model calculations; (3) completion of a pretest analysis; (4) performing the experiment; (5) re-evaluation of the pretest analysis in light of the actual experiment procedure; and (6) a post-test comparison of the experimental and analytical results performed by a Peer Review Panel.

3.3.5.2 Estimate of the Stress Altered Region

Estimates of the stress altered region will be performed in the first two experiments described in this Study using drift displacement data obtained with MPBXs (Study Plan Sections 3.1.5.3 and 3.2.5.2). The stress altered region will be better defined in the Sequential Drift Mining Experiment by using several other techniques to augment the data obtained with the MPBXs. Borehole permeability measurements performed before, during, and after the excavation of Drift B will be used to obtain the hydraulic quotient. Variations in the hydraulic quotient will be compared to estimate the extent of the effects of mining on the rock mass. Analysis of cross hole ultrasonic data obtained before and after mining Drift B will also be used to establish the effect of mining on the compressional velocities. Results from these three analyses will be compared and used to reevaluate the extent of the stress altered region determined in previous experiments using only MPBX data.

3.3.5.3 Excavation Efficiency Estimate

The analysis of the excavation efficiency activity will be performed in the same manner as described in Study Plan Section 3.2.5.3. It is expected that the experience gained in the construction of the Demonstration Breakout Rooms will improve the results of the controlled blasting used in the Sequential Drift Mining Experiment.

3.3.5.4 Air-Water Permeability Comparison

Permeabilities measured using air and water will be compared over the same borehole intervals using the equations developed by the U. S. Army Corps of Engineers (1980). These analyses will provide input to the development of relationships that can be used in modelling the unsaturated zone.

3.3.6 Representativeness of Results

The measurement stations selected for the Sequential Drift Mining Experiment will be located in the core facility at the main test level. The fracture density and orientation, and the variation in the lithophysae content is expected to be representative of the site-specific conditions found within the Yucca Mountain repository block (Nimick et al., 1988). Experience and information gained in the Demonstration Breakout Rooms Experiment will also be used to assess the effect of varying lithophysae on the mechanical response of the underground openings.

3.3.7 Performance Goals and Confidence Levels

The confidence levels for the model validation activities will be established by a Peer Review Panel as outlined in Section 6.4.10 and 8.3.2 of the SCP.

4.0 Application of Results

The Excavation Investigations Study Plan, Sections 1.1.1, 1.2.1 and 1.2.2 discuss the manner in which results from the Excavation Investigations Study experiments are applied to resolving regulatory requirements and the Information Needs and Investigations identified by the performance allocation process.

The data from this Study will be used to address or help to resolve a number of Information Needs and Investigations identified by the Nevada Nuclear Waste Storage Investigations (NNWSI) Project (Table 4.0-1). In situ stress measurements will be integrated with other in situ measurements and laboratory data to delineate the spatial distribution of thermal and mechanical properties and ambient stress of welded tuffs (SCP Investigations 8.3.1.15.1/2), Information pertaining to the effects of the mining operation on the extent and nature of the stress altered region, drift convergence rates and magnitudes, and stress changes will be used in Information Needs 1.11.3, 1.11.5, 4.2.1, 4.4.1, and 4.4.9 (SCP Sections 8.3.2.2.3/5, 8.3.2.4.1, and 8.3.2.5.1/9, respectively) to demonstrate that technology is available to construct repository-size rooms in welded tuffs having variable geologic and geomechanical characteristics.

4.1 Resolution of Site Programs

Results from the Excavation Investigations Study will provide useful corroborative data for a number of other studies. In situ experiments (SCP Section 8.3.1.15) associated with several study plans will be performed to provide estimates of the in situ rock mass properties that will be used to examine the validity of extrapolating laboratory determined properties to in situ conditions. Preliminary estimates of the variability of in situ properties (i.e. permeability, compressional and shear velocity, strength, etc.) at scales significantly larger

Table 4.0-1: Information Needs and Investigations Addressed During The Excavation Investigations Study

	Information Need/Investigation	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 Including Flexibility to Accommodate Site-Specific Conditions	8.3.2.2.3
1.11.5	Design Constraints to Limit Excavation-Induced Changes in Rock Mass Permeability	8.3.2.2.5
4.2.1	Site and Performance Assessment Information Needed for Design	8.3.2.4.1
4.4.1	Site and Performance Assessment Information Needed for Design	8.3.2.5.1
4.4.7	Design Analysis, 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 Underground Facility Construction, Operation, Closure, and Decommissioning	8.3.2.5.9
8.3.1.15	Studies to Provide the Required Information for Spatial Distribution of Thermal and Mechanical Properties	8.3.1.15.1
8.3.1.15	Studies to Provide the Required Information for Spatial Distribution of Ambient Stress and Thermal Conditions	8.3.1.15.2

than laboratory scales will further our understanding of the scale effects on the geomechanical characteristics. These in situ properties will facilitate interpretation of results obtained in other experiments designed to validate the thermomechanical model. The scaling relationships will be used to assess the effects of excavation on results of tests performed in the stress altered region and enhance our capability to select test locations that appear representative of the Yucca Mountain repository.

4.2 Resolution of Performance and Design Issues

The primary objective of the Excavation Investigations Study is to develop a data base for validating the rock-mass constitutive models that, when combined with a thermal model, will predict the thermomechanical response of the underground openings and help to develop an adequate design for stabilizing the underground facility. The models will be used to predict displacement magnitudes and the stress distribution induced by excavation and thermal loads.

Analysis of ground support requirements will consider the in situ stress state, joint spacing and orientation, and the effects of blasting on the rock mass.

5.0 Schedule and Milestones

5.1 Durations and Interrelationships of Excavation Investigations Study Experiments

The experiments planned in the Excavation Investigations Study will be performed in a progression that will permit the constitutive models to be gradually refined while proceeding with construction activities in a timely and cost efficient manner (Figure 5.1-1). The Shaft Convergence Experiment will provide initial information on variations in the geological and geomechanical characteristics that will be encountered in the

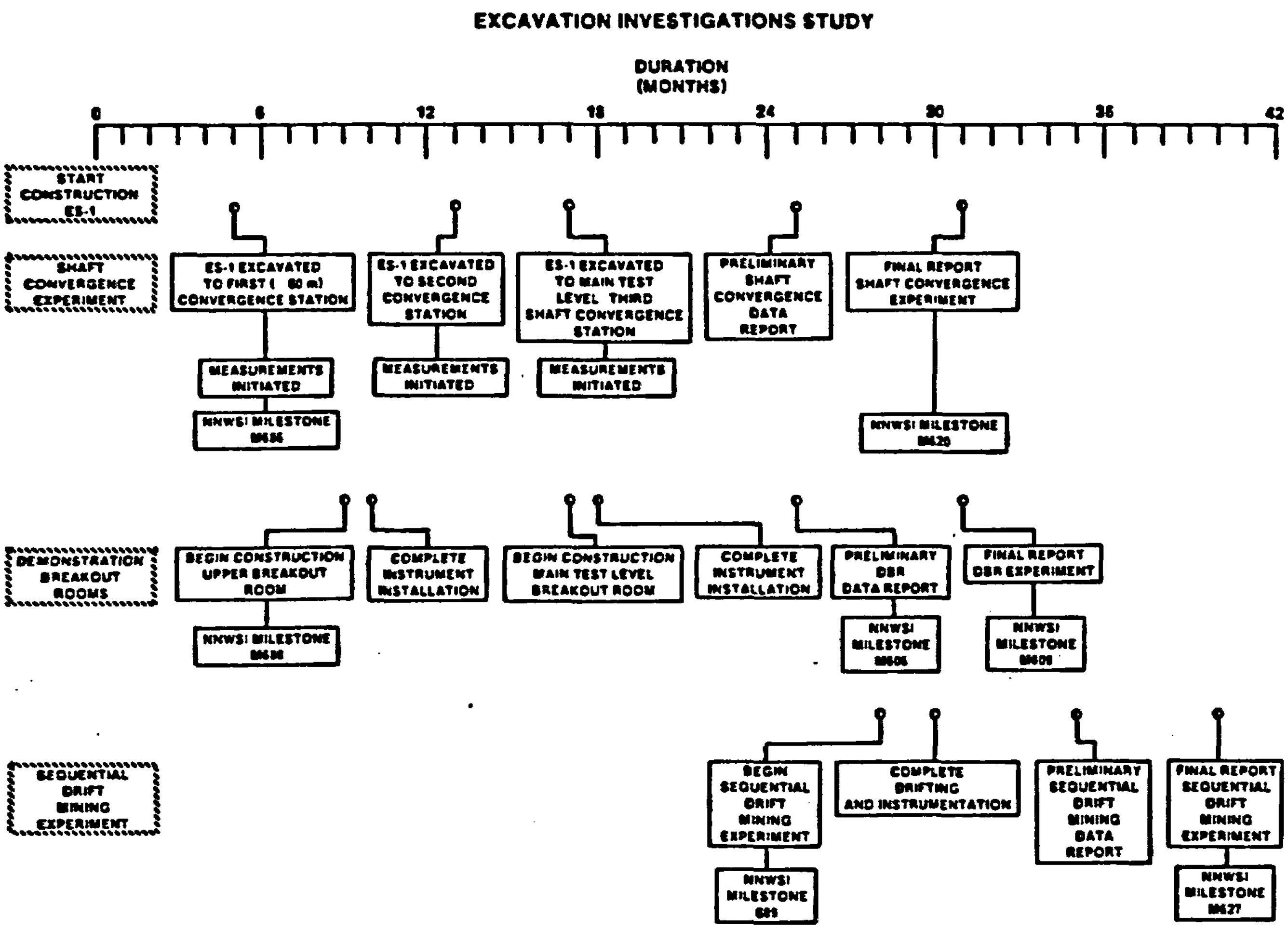

Figure 5.1-1: Duration Of Each Activity And Associated Major Milestones For The Excavation Investigations Study Experiments.

Exploratory Shaft Facility. These variations will be incorporated into the models, where appropriate, to predict displacement magnitudes for a preliminary assessment of the proposed design of the underground facility. The Demonstration Breakout Rooms Experiment will be used to demonstrate that repository-size rooms can be constructed in jointed welded tuffs, to exercise the rock-mass constitutive models and to provide an underground facility for additional in situ experiments. Experience gained in these two experiments will be an asset in designing and performing the Sequential Drift Mining Experiment. This experiment will be used to enhance the data base available for validating the rock-mass constitutive models.

5.2 Scheduling Relative to Other Studies

The Excavation Investigations Study experiments will be performed using the schedule proposed for the construction of the Exploratory Shaft Facility. Delays related to installing instrumentation during the Shaft Convergence Experiment may influence shaft construction schedules which may subsequently impact the remainder of the experiments scheduled in the underground facility. However, the instrumentation that will be installed during this experiment have been routinely used in numerous mining operations in the past and should not cause any unnecessary delays. Delays in the construction of the Demonstration Breakout Rooms could possibly impact experiments planned in other Studies that will be conducted in the Demonstration Breakout Rooms. The schedule for the Sequential Drift Mining Experiment should not impact other studies.

5.3 Schedule

The schedule for the activities associated with the Excavation Investigations Study (Sections 5.3.1, 5.3.2, and 5.3.3) is based on the initiation of these activities relative to the start of Exploratory Shaft construction and on the estimated duration of the activity. Delays in the start of shaft construction will have a commensurate effect on the activities planned in this Study. Figure 5.1-1 shows the duration of each activity and associated major milestones for the Excavation Investigations Study.

5.3.1 Shaft Convergence Experiment

Activity	Time (Months) From Start of ES Construction	Estimated Completion (Months)
Perform Shaft Convergence Measurements	+ 5	+ 17
Perform Post-Test Analyses	+ 8	+ 25
Report Results of Shaft Convergence Test	+ 25	+ 31

5.3.2 Demonstration Breakout Rooms Experiment

Perform Demonstration Breakout Rooms Testing	+ 9	+ 21
Perform Post-Test Analyses	+ 11	+ 25
Report Results of Demonstration Breakout Rooms Experiment	+ 25	+ 31

5.3.3 Sequential Drift Mining Experiment

Perform Sequential Drift Mining Experiment	+ 28	+ 30
Perform Post-Test Analyses	+ 29	+ 35
Report on Sequential Drift Mining	+ 35	+ 40

5.4 Milestones

5.4.1 Shaft Convergence Experiment

Milestone Number	Description and Criteria
M686	Begin Shaft Convergence Testing Letter
M620	Shaft Convergence Experiment Data Report SAND Report

5.4.2 Demonstration Breakout Rooms Experiment

M688	Begin Demonstration Breakout Rooms Experiment Letter
M606	Preliminary Testing Complete Letter
M609	Demonstration Breakout Room Experiment Complete SAND Report

5.4.3 Sequential Drift Mining Experiment

Milestone Number	
M689	Begin Sequential Drift Mining Experiment Letter
M627	Complete Sequential Drift Mining Experiment Report SAND Report

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APPENDIX

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