YUCCA MOUNTAIN PROJECT

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Revision Number 0

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Study Plan for the

Systematic Acquisition of Site-Specific Subsurface Information

Site Characterization Plan
Study 8.3.1.4.3.1.

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December 2, 1992

ABSTRACT

The Yucca Mountain site in southern Nevada has been identified as a potential location for a high-level nuclear waste repository. This study plan describes a investigative program to acquire core samples and subsurface geologic information from within and immediately adjacent to the proposed repository block in a systematic fashion, and to evaluate on a preliminary basis the adequacy of these samples and information in representing the geologic environment of the repository. In its complete context, which includes providing core samples to a large number of other SCP studies for laboratory testing above and beyond the testing proposed in this particular study plan, this Study will provide a significant fraction of the total information required for repository design and performance assessment. The broad topical focus of this Study on a single area, the repository block itself, provides one means of integrating a variety of site characterization efforts that are more focused on particular geologic processes or phenomena.

This Study contains one formal activity, the Systematic Drilling Program. This drilling program, which is integrated with other Yucca Mountain Project site drilling efforts outside the immediate repository block, proposes to drill an initial phase of 12 holes to depths varying between 2,000 and 3,000 ft (600 to 900 m) below the surface depending mostly on surface topography. Drill holes will penetrate at least 300 ft (100 m) into the saturated zone at Yucca Mountain, as required by the Ground Water Travel Time Issue in the SCP. Core from these drill holes will be logged as part of this study for information regarding the geology, stratigraphy, rock characteristics, and engineering properties of the materials composing the repository environment. These geologic logs will directly contribute to numerous design and performance assessment activities. Geophysical logging of the completed drill holes will provide additional information regarding the subsurface character of the rocks at Yucca Mountain. Core samples from the surface-based drilling program will be tested under this Study for a number of matrix properties that are quantitative measures of the framework geology of Yucca Mountain. Additional core samples will be obtained from the underground workings of the Exploratory Studies Facility as required to describe spatial variability in the subsurface. These properties include porosity, bulk density, particle density, and saturated matrix permeability. The hydrologic state variables of water content and saturation will be determined as well, since these properties must be determined prior to other testing, if they are to be obtained at all. This Study will also provide core samples to a large number of other SCP studies for additional laboratory testing. Finally, this Study will use graphical, statistical, and geostatistical techniques, in addition to geologic interpretations, to provide a first-pass estimate of the adequacy of drill hole density and down-hole sampling patterns in characterizing the repository block. This evaluation will be performed on an on-going basis so that sampling patterns and drill hole spacings can be adjusted if required.

Section 1 describes the purpose and objecives of this Study and the regulatory justification for obtaining the information. Section 2 describes the technical rationale and justification for the various activities proposed. This section also discusses the constraints on the Study and details the interrelationships of this Study with many other SCP studies. Section 3 provides a description of the actual technical activities and how these activities will be accomplished. Section 4 summarizes how the geologic information and laboratory testing results will be applied in the resolution of design and performance assessment issues. Finally, Section 5 presents schedules and associated milestones.

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1.0 PURPOSE AND OBJECTIVES OF THE STUDY

The U. S. Department of Energy is conducting studies of a potential site at Yucca Mountain, Nevada, which has been proposed as the location for a high-level nuclear waste repository. Geologic, hydrologic, and geotechnical information about the site will be required for both engineering design studies and activities directed toward assessing the waste-isolation performance of the overall repository system. Acquisition of basic geologic and other information is the focus of site characterization, a multidisciplinary effort being conducted on behalf of the U. S. Department of Energy by several federal agencies and other organizations as part of the Yucca Mountain Site Characterization Project. Figure 1.1 shows the location of the general Yucca Mountain area in southern Nevada. The location of the proposed underground facilities, also shown on Figure 1.1, represents preliminary design concepts developed prior to detailed site characterization.

The Yucca Mountain site consists of a gently-eastward dipping sequence of volcanic tuffs, principally welded ash flows with intercalated nonwelded and reworked units. Various types of alteration phenomena, including devitrification, zeolitization, and the formation of clays, have been superimposed upon the primary lithologies. The units are variably fractured, and faulting has offset the various units, locally juxtaposing markedly different lithologies. A comparison of differing stratigraphic terms that have been used to describe the rocks at Yucca Mountain is shown in Figure 1.2. The potential repository would be excavated in the central portion of the Topopah Spring Member of the Paintbrush Tuff. Accordingly, most design interest is focused on the Topopah Spring Member and immediately adjacent units. By comparison, the waste-isolation performance of the repository system must be evaluated within a larger geographic region; compliance with regulations generally must be demonstrated at what is termed the *accessible environment* in 10 CFR 60.2, or outer limit of the controlled area (Figure 1.1).

The region encompassed by this study is contained entirely within the controlled area, the outer limits of which define the beginning of the accessible environment. In general, this study is further restricted to the location of the proposed underground facilities in keeping with a general engineering orientation. Water and any migrating radionuclides escaping from the repository would necessarily travel through the rocks being investigated by this study. This region is referred to for convenience as the *repository block* in recognition of the three-dimensional nature of the study. Other studies sponsored by the Department of Energy are addressing the region outside the proposed location of the underground facilities.

1.1 Purpose of the Study Plan

The purpose of this Study Plan is to describe how site-specific subsurface information will be acquired for use in the development of three-dimensional models of rock characteristics within the repository block. This Study constitutes one part of SCP Investigation 8.3.1.4.3 (Development of Three-Dimensional Rock Characteristics Models at the Repository Site). This SCP Study 8.3.1.4.3.1, entitled "Systematic Acquisition of Site-Specific Subsurface Information", contains one Activity, numbered 8.3.1.4.3.1.1, the Systematic Drilling Program. The plan lays out the geostatistical principles and practices which will guide the drilling program to acquire systematic and unbiased sampling of the physical and chemical properties of the rock mass being studied. Note that throughout this document, references to "SCP Investigations," Studies" or "Activities," and

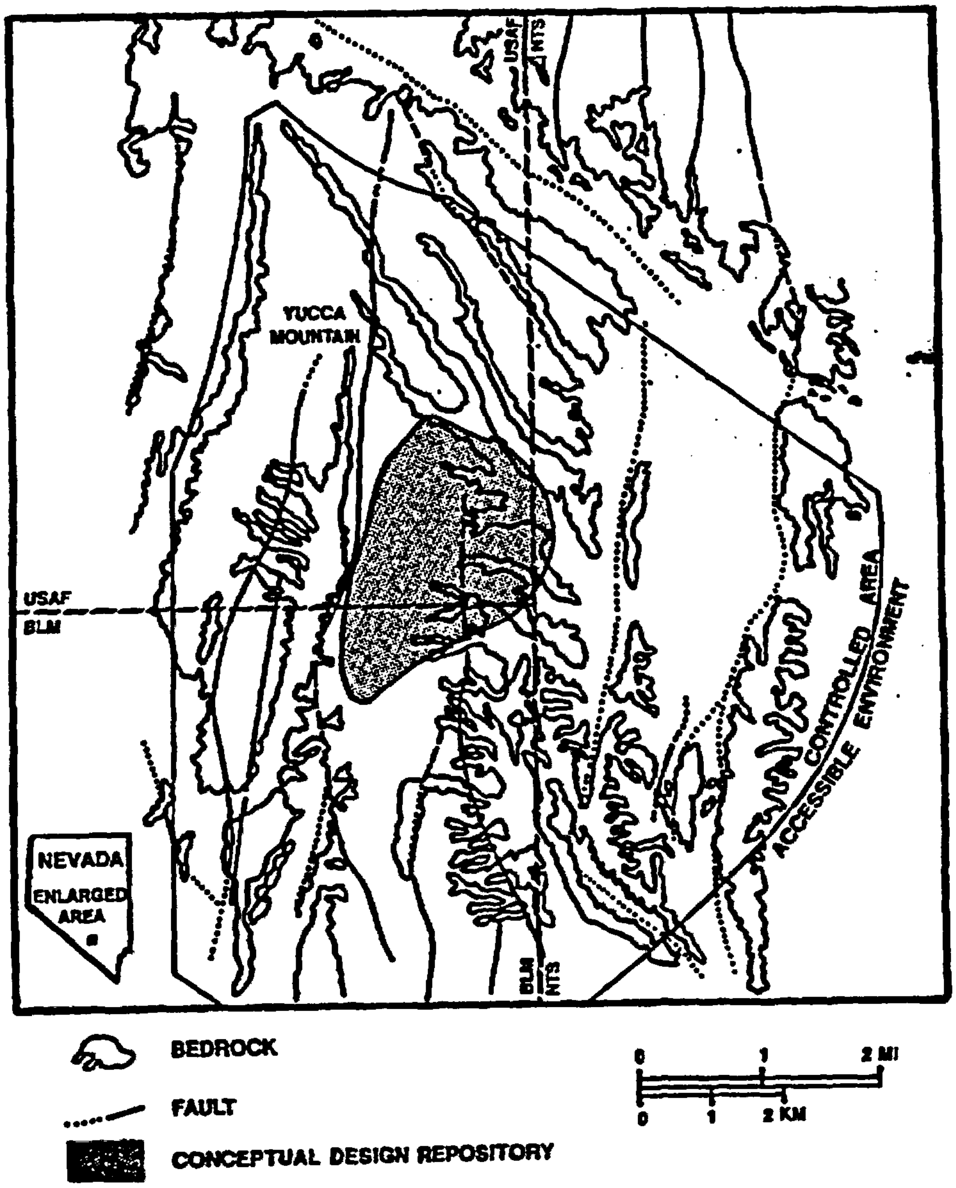

Figure 1.1 Index map showing the location of the potential Yucca Mountain repository site in southern Nevada

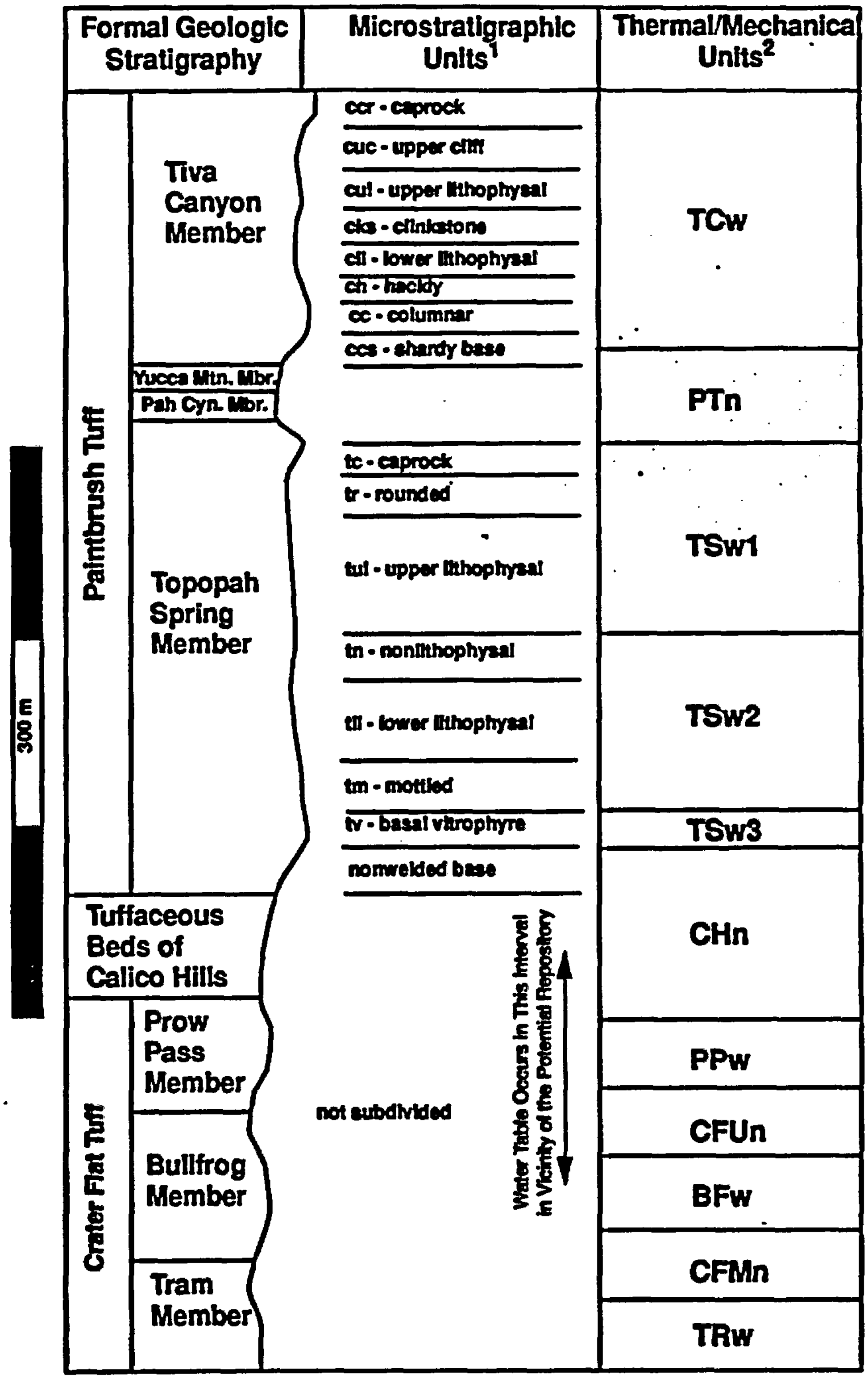

Figure 1.2 Comparative stratigraphic terminology in common usage at Yucca Mountain. [1]modified after Scott and Bonk (1984) for the immediate repository vicinity; [2]from Ortiz and others, 1985. Thicknesses and "weathering profile" are highly schematic; character varies with location.

the associated numeric strings refer to the Yucca Mountain Site Characterization Plan (DOE, 1988a). The Site Characterization Plan describes the regulatory and general technical rationale for the complete site characterization program, and it provides insight into the integration of the various activities into a comprehensive understanding of the Yucca Mountain site.

This Study is unusual in its statistical and geographic focus. Many other studies focus on evaluating phenomena or processes, in order to provide regulatory assurance that these phenomena and processes are adequately understood. By contrast, this study has a unique areal focus centered on the conceptual-design underground facilities, and it seeks to provide assurance that a variety of geologic and other parameters are adequately represented in a geostatistical sense by samples and descriptions taken in the immediate location of the potential repository. This representativeness will help assure adequate assessment of the performance of the site, given understanding of the processes evaluated in other studies.

The emphasis of this study on the "site" provides a useful and necessary unifying framework for integrating a multidisciplinary engineering study such as the Yucca Mountain Project. Understanding the importance of this study to the overall site characterization program and the reasons for implementing the study in the manner described in this document is only possible by describing the work in its overall context. Throughout this Study Plan, an effort is made to describe (1) the work to be conducted directly under this Study Plan and (2) work conducted by other SCP studies that is directly allied with the objectives of the higher-level investigation of which this study is a part. The level of detail provided for item (1) is necessarily significantly greater than that associated with item (2). Detail regarding the specifics of work conducted by other SCP studies may be found by reference to the appropriate study plans. Discussion of issues related to the integration of this study with other site characterization investigations and individual studies is provided in relevant sections of this Study Plan. An overview of the required integration is given in Section 2.5.

1.2 Objectives of the Study

The objective of the Systematic Drilling Program is to provide for the systematic collection of rock samples and the description of the geological and geophysical characteristics of the repository block by drilling at least twelve surface-based drill holes (Section 3.1). The currently proposed positions for these holes are shown in Figure 1.3, with the prefix "SD-." Other hole locations shown are part of other SCP Studies. Their locations, and the sampling program for them have been taken into account in designing the SD hole layout. Together, all holes shown form an integrated drilling program for the Yucca Mountain Project.

Holes of the Systematic Drilling Program will be targeted to a depth of 300 ft (100 m) below the static water level, passing through the repository horizon and sampling it as well as the overlying and underlying rock units. The intended depth of the holes varies from 1700-2300 ft (500-700 m), and depends primarily upon surface topography with respect to the water table. The requirement of 300 foot (100 m) below the static water level originates in Section 8.3.5.12 of the SCP (Table 8.3.5.12-3). Selected locations may be drilled to approximately 3,000-ft (900-m) depths in order to provide core samples of deeper units (tentatively SD-1, SD-7, H-7), as requested by other studies (SCP Study 8.3.1.3.2.1). Holes will be continuously cored, and a suite

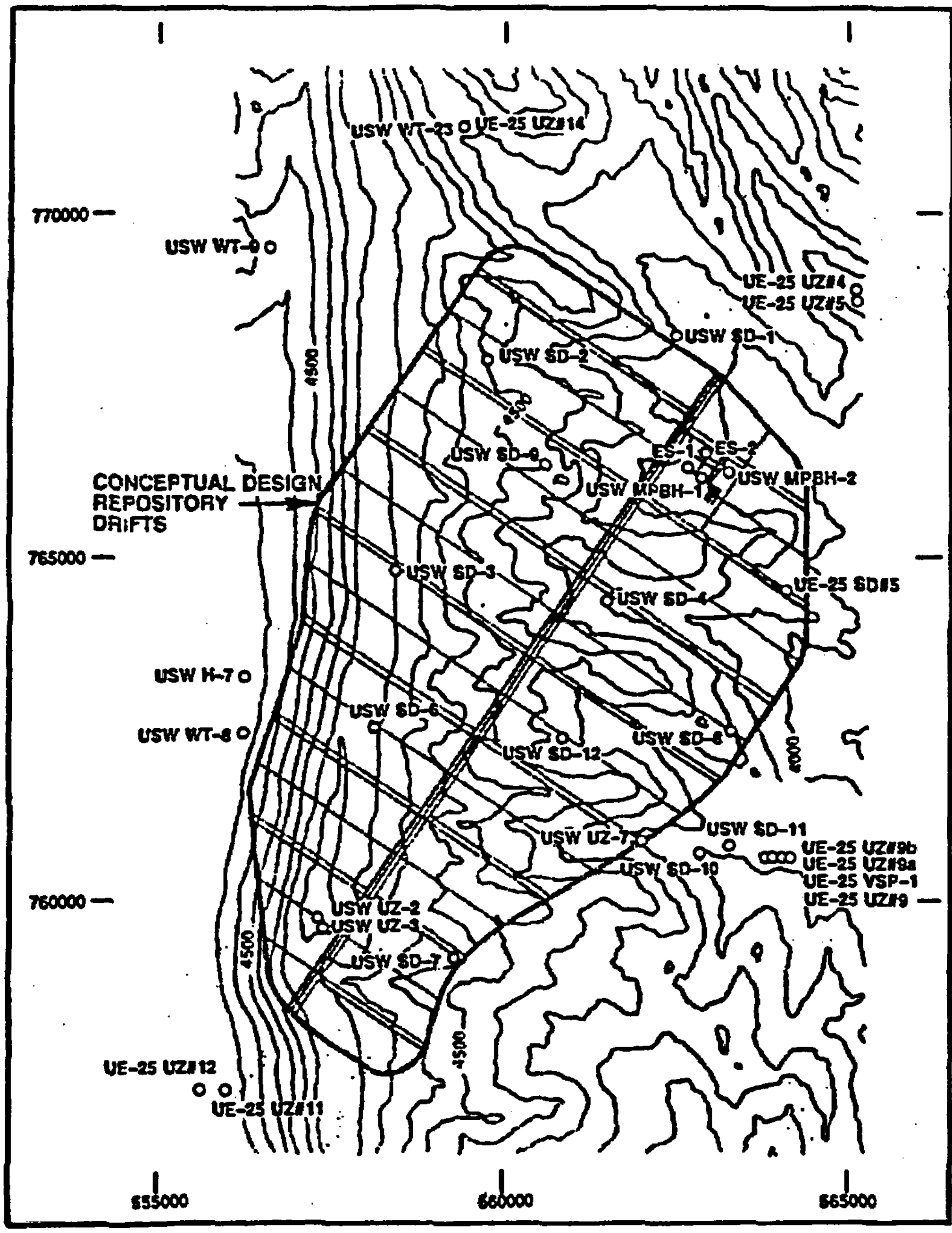

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Figure 1.3 Map of the potential Yucca Mountain repository site showing locations of proposed Systematic Drilling Program holes.

of geophysical logs (Section 3.3) will be obtained from each hole.

Core from these drill holes will provide the physical materials for description of the subsurface geology (Section 3.2). The intact core will be examined carefully and logged in detail for general lithologic, structural and other geologic information, and for features important to engineering design and performance assessment. The drill core will also provide physical specimens for laboratory testing of hydrologic, thermal, and mechanical rock properties. Specimens will be analyzed for mineralogic and geochemical purposes as well. A limited suite of testing for rock properties of general utility in describing the framework of the site will be performed directly by this study (Section 3.4); significant additional testing will be performed by other, more specialized (process-oriented) studies as described in later sections. The drill holes themselves will provide access to the subsurface environment of Yucca Mountain for potential use by other studies.

In addition to the surface-based activities, this study will collect additional samples and supporting information in a systematic manner from the underground workings of the Exploratory Studies Facility (ESF). These samples will be used, as needed, to supplement the description of spatial continuity patterns in the (stratigraphically) horizontal plane in the two units of principal interest within the Yucca Mountain Project, namely the Topopah Spring Member of the Paintbrush Tuff (the repository horizon) and the tuffaceous units of Calico Hills (the designated "primary barrier" to waste migration). Samples will be collected as short cores or subcored hand specimens from the ribs of appropriate underground workings, and their location keyed to geologic maps produced by other studies (SCP Activity 8.3.1.4.2.2.4). Laboratory testing of these samples will be identical to that described in the preceding paragraph.

Finally, the collective results of this study will be evaluated (Section 3.5) on an on-going basis to ensure that drilling and sampling are being conducted in an effective manner and that the data and information are likely to be adequate for performance assessment and design activities. This on-going evaluation may result in changes to the proposed drilling, sampling, and testing programs -- not only for this study, but for relevant aspects of other Project drilling efforts as well.

1.3 Use of Study Plan Results

Taken in context, the Systematic Drilling Program and the testing studies that depend upon it will provide a major portion of the total information and physical sample material from the limited volume of rock containing the proposed repository. Holes to be drilled as part of the Unsaturated Zone Percolation Study (8.3.1.2.2.3; "UZ-" prefix in Figure 1.3) serve an identical purpose for rocks in the immediate vicinity (but generally outside) of the repository block. Only the Exploratory Studies Facility will provide a similar volume of samples or information from within the repository block, and this material will be restricted to the location of the ESF excavations. In this respect, the Systematic Drilling Program -- particularly when combined with the holes to be drilled as part of the Unsaturated Zone Percolation Study -- may be viewed as providing extensive (areal) coverage, whereas the Exploratory Studies Facility provides intensive detail.

In addition to the descriptive site data that will be generated directly by this study, a significant amount of testing and other data gathering will be conducted by other site characterization studies using core samples or the drill holes themselves. A brief description of these studies is presented in Table 1.1. Additional discussion of the interrelationships of these various studies is provided in Section 2.5.

Table 1.1 Other SCP Studies Depending upon the Systematic Drilling Program for Data and/or Sample Materials

Study Name and SCP Section	Brief Description
Unsaturated Zone Percolation; 8.3.1.2.2.3	The matrix hydrologic properties testing activity of this study will determine matrix rock properties and hydrologic state variables using core samples.
Hydrochemical Characterization of the Unsaturated Zone; 8.3.1.2.2.7	The compositions of aqueous and gas phases will be determined for fluids from core samples.
Mineralogy, Petrology, and Chemistry of Transport Pathways; Study 8.3.1.3.2.1	The three-dimensional distribution of mineral types, compositions, and abundances and petrographic textures will be determined from core samples.
Three-Dimensional Rock Characteristics Models; 8.3.1.4.3.2	Computer-based three-dimensional models will be constructed using core-log and rock properties data obtained from core samples
Laboratory Thermal Properties; 8.3.1.15.1.1	Thermal conductivity, heat capacity, and supporting rock properties will be measured on core samples.
Laboratory Thermal Expansion; 8.3.1.15.1.2	Thermal expansion behavior of tuff and the spatial variability of this behavior will be studied using core samples
Laboratory Determination of Mechanical Properties of Intact Rock; 8.3.1.15.1.3	Mechanical properties and the spatial variability of those properties for intact (non-fractured) rock will be estimated using core samples.
Laboratory Determination of Mechanical Properties of Fractures; 8.3.1.15.1.4	Mechanical properties and the spatial variability of those properties for fractures will be estimated using core samples.
Characterization of Site Ambient Stress Conditions; 8.3.1.15.2.1(.1)	The magnitude and spatial variability of horizontal stresses will be determined by measuring biaxial strain relief immediately after removal of selected core samples.
Seal Material Properties Development; 8.3.3.2.2.1	Hydraulic conductivity testing will be performed on samples of crushed Topopah Spring Tuff

A primary use of the information resulting from the Systematic Drilling Program is in the construction of three-dimensional models of the site for use in performance assessment and design. Although this study does not construct such models, the study is part of an investigation (Investigation 8.3.1.4.3; Development of Three-Dimensional Models of Rock Characteristics at the Repository Site), which contains a study (Study 8.3.1.4.3.2, Three-Dimensional Rock Characteristics Model) that is intended to be one of the major geologic modeling activities of the Yucca Mountain Project. Accordingly, the current Study has been carefully designed to provide much of the information needed to model the immediate repository block. The need for site-specific information reflects this close linkage to the parallel modeling activity. Modeling of the Yucca Mountain site necessarily will need to include data and information from a variety of sources including surface mapping, geophysical investigations, and underground testing, in addition to the information from this study.

Rock characteristics models are not an end in themselves. These models are to be used in performance assessment and design activities that are directed toward licensing documents. Thus, the information to be gathered by the Systematic Drilling Program will be used by a large number of Project participants outside the site program, *per se*. Because the use of this information by design engineers and performance analysts will be so widespread, it is not easy to compile a tabular listing similar to Table 1.1, which refers only to site studies listed in Chapter 8 of the SCP. These performance assessment and design uses are more easily described by reference to design and performance "issues" and "information needs," as is done in the following section (Section 1.4.1).

1.4 Regulatory Rationale and Justification for the Information to be Collected

1.4.1 Resolution of Performance and Design Issues

The performance allocation process has been used by the Yucca Mountain Project to establish appropriate issue resolution strategies. A general discussion of the performance allocation process is provided in SCP Section 8.1, and the issues to be resolved are described in SCP Section 8.2.1. Issue resolution strategies and details of performance allocation for each design and performance assessment issue are summarized in SCP Section 8.2 and provided in full detail in SCP Sections 8.3.2 through 8.3.5. The principal performance assessment and design issues, and corresponding information needs, that will be addressed using the information and data obtained in this study are summarized in Table 1.2.

Table 1.2 Issues, Information Needs, and Parameters Generated by the Systematic Drilling Program and Associated Testing Programs

Issue 1.1	Will the mined geologic disposal system meet the system performance objectives for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13?
Information Need 1.1.1	Site information needed to calculate releases to the accessible environment.
Issue 1.6	Will the site meet the performance objective for pre-waste emplacement ground-water travel time as required by 10 CFR 60.113?
Information Need 1.6.1	Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path.
Issue 1.8	Can the demonstrations for favorable and potentially adverse conditions be made as required by 10 CFR 60.122?
Issue 1.10	Have the characteristics and configuration of the waste packages been adequately established to (a) show compliance with the post-closure design criteria of 10 CFR 60.135, and (b) provide information for the resolution of the performance issues?
Information Need 1.10.4	Post-emplacement near-field environment.

Table 1.2 Issues, Information Needs, and Parameters Generated by the Systematic Drilling Program and Associated Testing Programs

Issue 1.11	Have the characteristics and configurations for the repository and repository engineered barriers been adequately established to (a) show compliance with the post-closure design criteria of 10 CFR 60.133, and (b) provide information for the resolution of the performance issues?
Information Need 1.11.1	Site characterization information needed for design.
Issue 1.12	Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the post-closure design criteria of 10 CFR 60.134, and (b) provide information for the resolution of the performance issues?
Information Need 1.12.1	Site, waste package, and underground facility information needed for design of seals and their placement methods.
Issue 2.4	Can the repository be designed, constructed, operated, closed, and decommissioned so that the option of waste retrieval will be preserved as required by 10 CFR 60.111?
Information Need 2.4.1	Site and design data required to support retrieval.
Issue 2.7	Have the characteristics and configurations of the repository been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.130 through 60.133 and (b) provide information for the resolution of the performance issues?
Issue 4.2	Are the repository design and operating procedures developed to ensure nonradiological health and safety of workers adequately established for the resolution of the performance issues?
Information Need 4.2.1	Site and performance assessment information needed for design.
Issue 4.4	Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues?
Information Need 4.4.1	Site and performance assessment information needed for design.

Numerous information needs (Table 1.2) make reference to "site information" required to resolve various performance and design issues. The Systematic Drilling Program is intended as one of the primary sources of descriptive site information for the entire project. Geologic description of core from the Systematic Drilling Program (a direct product of this study) is a source of information regarding the three-dimensional location and extent of stratigraphic units and the lithologic character of those units, faults, joints, mineralogy, and certain engineering properties of the rock mass. Core from the Systematic Drilling Program will be used not only by this study, but core samples will be tested by numerous other studies within the Yucca Mountain Project to determine quantitative values of various rock properties necessary to describe the site and to resolve the design and performance issues. Both geologic descriptions obtained from core and quantitative rock properties data are required to construct three-dimensional rock characteristics models of the site; such models are essential to engineering design and performance assessment. Discussion of these inter-study relationships and a conceptual logic diagram are provided in Section 2.5.

1.4.2 Regulatory Requirements

This Study will provide some of the information needed to demonstrate compliance with several key regulations outlined in the Code of Federal Regulations (CFR), Title 10, Parts 60 and 960. The discussion of Siting Criteria (10 CFR 60.122) presents a list of favorable and potentially adverse conditions relative to waste isolation. Identifying the extent to which the Yucca Mountain site satisfies the requirements of this code section is the substance of Issue 1.8 (Table 1.2). The descriptive information acquired as part of the Systematic Drilling Program is directly relevant to the criteria given in sections 122(b)(3), (4), (5), (7), and (8) and sections 122(c)(3), (7) through (11), (17), and (20) through (24). Design criteria for the underground facility are specified in 10 CFR 60.133. The repository design depends heavily upon a description of the site itself. In particular, the Systematic Drilling program will provide information relevant to facility layout (60.133(a)), flexibility of design (60.133(b)), ground stability (60.133(e) and (f)), and stability in the presence of thermal loading (60.133(i)).

An extensive listing of qualifying and disqualifying conditions, and favorable and potentially adverse conditions relevant to siting a geologic repository is also contained in 10 CFR 960. Most of these conditions are specified in 10 CFR 960.4-2, Technical Guidelines. The Systematic Drilling Program and the other studies that make use of core obtained from the drilling effort will provide information that is directly applicable to the following code sections: Geohydrology (960.4-2-3), Geochemistry (960.4-2-2), Rock Characteristics (960.4-2-3), Dissolution (960.4-2-6), Tectonics (960.4-2-7), and Natural Resources (960.4.2-8.1). The Yucca Mountain Project has adopted a policy of periodically reviewing whether ongoing site characterization has identified any of the disqualifying conditions specified by this code section (for example, Younker and others, 1992).

Some data resulting from the Systematic Drilling Program will also be directly applicable to the sections of 10 CFR 960 that deal with the costs of construction and operation. These sections are essentially a restatement of the need for data on rock characteristics, hydrology, and tectonics described in the preceding paragraph. The cited types of information will be required for estimating the anticipated costs of repository construction and operation as part of an on-going repository program, even if the relative costs at Yucca Mountain is no longer a selection criterion *vis-a-vis* other repository sites as originally envisioned in 10 CFR 960.

2.0 RATIONALE FOR THE SYSTEMATIC DRILLING PROGRAM STUDY

2.1 Technical Rationale and Justification

2.1.1 General Rationale for the Site Drilling Effort

The geology and rock characteristics of the repository block may be inferred from numerous existing, pre-site characterization sources of information: surface geologic mapping, analysis of geologic cross sections, sparse existing drill holes, and similar sources. However, these data are not sufficient to develop the detail -- and the confidence in that detail -- that is required for a license application. Additional characterization is required through drilling and sampling of the repository block itself.

McBratney and Webster (1983, p. 178) refer to numerous other studies that have concluded that "systematic sampling, i.e., at regular intervals, along a transect or on a grid, [gives] the most precise estimates [of a variable of interest] for a given effort." Systematic, gridded drilling patterns are widely accepted as the standard method of site characterization in mining applications. Journel (1983) and Deutsch (1989) discuss preferential sampling patterns in the earth sciences and the consequences of such non-systematic sampling when estimating spatial averages or distributions of values. Such non-systematic sampling commonly occurs as a result of the need to characterize specific, recognized features of a site, especially to identify and characterize potentially adverse or disqualifying features that might be present (for example, 10 CFR 960.4-2). For example, drill holes UZ-11 and UZ-12 (Figure 1.3) are paired holes to be drilled for cross-hole hydrologic testing on opposite sides of the Solitario Canyon fault. Other non-systematic sampling may occur as a consequence of drilling conducted to evaluate processes operative in the site region in order to understand site performance. The program of work described in the SCP attempts to improve the state of knowledge by developing a systematic, yet integrated, drilling program for site characterization.

Prior characterization of the Yucca Mountain site consisted of a program of features-oriented sampling, focused primarily on determining the preliminary ability of the site to meet the licensing requirements. The program did not attempt to provide the systematic description of the site properties needed for design and performance assessment. Design and performance assessment need to evaluate the heterogeneity of rock characteristics and the effect of such heterogeneity on performance. Systematic and unbiased data, such as will be acquired by this Study, are required for these performance-related analyses.

The integrated drilling effort capitalizes upon the need for continuing investigation of various features and processes critical to evaluation of the site (for example, faults as preferential pathways, unexpected perched water zones, etc.). The UZ- and WT- holes shown in Figure 1.3 are good examples of the continuing feature-of-interest approach. The feature- and process-oriented drill holes planned by other studies have been combined with the holes proposed as part of the Systematic Drilling Program so that statistical benefits are gained from the pattern of coverage. The combined pattern of coverage consists of a partial grid covering the immediate repository block, which achieves systematic sampling without the additional drilling that would be required if all activities were conducted in isolation. Although any drilling may identify new feature which require additional drilling, the Systematic Drilling Program is primarily intended to acquire systematic description of design and performance assessment characteristics in the vicinity of the repository excavations, with principal responsibility for identifying additional "features" of interest remaining with the studies focused on those particular topics.

A general discussion of how the overall drilling program will be integrated is contained in section 8.3.1.4.1 of the SCP. A description of how specific other drilling efforts mesh with and provide additional information to the Systematic Drilling Program is provided in Table 2.1. Additional details of the mechanics of each project drilling program can be found in the Surface-Based Investigations Plan (DOE, 1988b).

Table 2.1 Summary Description of Drilling Programs from the SCP and Notes on Their Role in the Integrated Site Drilling Effort

SCP Drilling Program	Brief Description	Hole No.
Systematic Drilling Program; Study 8.3.1.4.3.1 (*This Study*)	The Systematic Drilling Program consists of an initial set of 12 SD- prefix holes. Some holes provide areal coverage of the repository block; others provide in-fill detail for geostatistical purposes.	SD-1 through SD-12
Unsaturated Zone Percolation; Study 8.3.1.2.2.3	The UZ Percolation Drilling Program consists of approximately 17 holes to be drilled, redrilled, or deepened. Some 11 UZ- prefix holes have been located adjacent to the repository block to provide additional data for geostatistical purposes.	UZ-2, -3, -4 -5, -7, -9, -9a, -9b, -11, -12, -14
Saturated Zone Flow System; Study 8.3.1.2.3.1	The Saturated Zone Program will drill a single H-series hole for pump testing and hydrologic monitoring. The study will also drill 8 WT- series holes for better definition of the regional potentiometric surface. Hole H-7 and two of these WT- holes (WT-8 and WT-9) are located adjacent to the repository block to provide additional data for geostatistical purposes.	H-7 WT-8 WT-9
Exploration Program (for soil and rock properties at surface facilities) Study 8.3.1.14.2	A large number of shallow core holes are proposed at intervals along the alignment of proposed access ramps to the underground facilities	NRG-1 thru 6 SRG-1 thru 5
Multipurpose Boreholes; Study 8.3.1.2.2.4.9	Two multipurpose boreholes (MPBH- prefix) were to be drilled near the Exploratory Shaft. These two holes are located within the repository block, and as such, would provide additional data for geostatistical analysis. The current status of the MPBH holes in the modified Exploratory Studies Facilities is uncertain.	MPBH-1 MPBH-2
Vertical Seismic Profiling; Study 8.3.1.4.2.2.5	One VSP- prefix borehole is planned for instrumentation related to vertical seismic profiling studies. This hole has been incorporated into the site-coverage pattern for geostatistical purposes,	VSP-1 (now UZ-16)

Table 2.1 Summary Description of Drilling Programs from the SCP and Notes on Their Role in the Integrated Site Drilling Effort

SCP Drilling Program	Brief Description	Hole No.
Stratigraphic Studies; Study 8.3.1.4.2.1	Three additional G-series holes are planned to acquire regional stratigraphic information. These holes are located too far from the repository block to provide much geostatistical data. However, qualitative and interpretive information from these holes will be incorporated as warranted.	G-5 G-6 G-7
Mineralogy, Petrology, and Chemistry of Transport Pathways Study 8.3.1.3.2.1	One G-series hole is planned to obtain samples of deep geologic units for geochemical analysis. See notes on G- series drill holes.	G-8
Characterization of Volcanic Features Study 8.3.1.8.5.1	Four V- holes are planned to investigate four aeromagnetic anomalies that may represent buried volcanic or intrusive features to the west of the site. See notes on G- series drill holes.	V-1, V-2, V-3, V-4

2.1.2 Proposed Approach to the Study

This Study proposes to drill a suite of core holes, described below, to provide areal coverage of the repository block and immediately adjacent regions. Geologic and engineering information will be obtained by logging the core from these holes. Geophysical logging of the drill holes will provide additional geologic information and independent confirmation of the geologic descriptions of the repository site. These activities will provide a large portion of the "site information" referred to in the various issues and information needs listed in Table 1.2. Specific "parameters" or rock characteristics to be measured and/or described as part of this work are discussed in greater detail in Section 3 of this Study Plan.

In addition to the descriptive geologic and engineering information to be obtained by core description or measurements taken from the core as a whole, this study will also obtain a set of laboratory measurements of rock properties on samples taken from the core. These laboratory rock characteristics consist of basic matrix properties of the rock mass and *in situ* conditions, which would otherwise deteriorate, that are essential to a first-order understanding of the site. These rock properties are sometimes referred to as "framework properties" elsewhere in this Study Plan. Specific properties to be measured are discussed in greater detail in Section 3 of this Study Plan (see also Table 3.4). Laboratory properties will be measured on the same physical specimen, whenever feasible, to allow direct inter-variable correlations of rock properties. The interrelationship of material-properties testing to be conducted as part of this study to similar material-properties testing to be conducted as part of other, process-oriented SCP studies (see Section 1.1) is discussed at greater length below in Section 2.5.

Supplemental samples will also be collected from appropriate underground workings of the Exploratory Studies Facility and subjected to the same laboratory testing procedures described in the preceding paragraph. This aspect of the sampling and testing effort described in this Study Plan is secondary to the main portion of the work, which consists of the surface-based portion of the Systematic Drilling Program activity. The scope of the proposed Exploratory Studies Facility has expanded significantly since development of the SCP (DOE, 1988a). The extensive network of underground drifting in both the repository horizon itself (Topopah Spring Member) and the primary barrier to waste migration (tuffs of Calico Hills) provides an excellent opportunity for the "systematic acquisition of site-specific subsurface information" (title of this study) that was not contemplated during development of the SCP.

This Study Plan explicitly holds that the rock properties of interest to the Yucca Mountain Project are spatially correlated, and thus rock samples do not represent independent samples from some statistical population. This proposition, which is well supported by preliminary scoping studies conducted at the Yucca Mountain Site and by general geologic knowledge (see Section 2.1.3), renders many classical statistical methods for determining the number of samples required for characterization unusable or of questionable applicability. Additionally, discussion of sampling strategy is complicated by the need to characterize geologic materials that potentially may be considered to represent many different and non-exclusive "populations." Each of the stratigraphic entities described in Figure 1.2 could represent a different population for some purposes. Unquestionably, other populations could be defined as well. A general utility program of drilling and sampling, such as this study, must necessarily be a compromise among the requirements suggested by many diverse users of the final data. Discussion of the rationale for the proposed numbers of drill holes and down hole samples is presented in Section 2.2. Some of the various statistical techniques and methods that have been used to develop these current plans, and which will be used as the Study progresses to confirm or revise those plans, are described in Section 3.5.

2.1.3 Scoping Studies

A number of scoping studies have defined spatial correlation structure in Yucca Mountain tuffs using systematic sampling transects and grids covering selected accessible outcrops of Yucca Mountain tuffs (Istok and others, 1991, Rautman, 1991; Rautman and others, 1991; Rautman and Flint, 1992). Geostatistical evaluation of hydrologic properties (Rautman and Flint, 1992) provide valuable planning information for this activity and for other sampling programs. Scoping studies also serve as prototyping efforts to test and refine procedures prior to the conduct of quality affecting work.

2.2 Rationale for the Scale, Location, Number, and Type of Data Collection Activities

2.2.1 Scale

The scale of data collection activities of the Systematic Drilling Program is controlled principally by the size of the repository block (approximately 2.5 mi^2 or 6.5 km^2; Figure 1.3). Coverage of the entire area of interest is necessary to identify and describe broad features and changes in those features across that area. Within the area of interest, the density of drilling and sampling is determined by the general requirement to characterize adequately the spatial variability of the repository block, and plans have been derived from estimates of degree of spatial correlation developed from scoping studies (Section 2.1.3). Data from the Systematic Drilling Program will be evaluated iteratively, to verify that the drilling density is adequate (see Section 3.5). In general, greater spatial variability will require more intensive (more closely spaced) drilling and sampling.

2.2.2 Location and Number of Drill Holes

The requirement to provide systematic areal coverage of the entire repository block places constraints on drill hole spacing, and the need to identify spatial correlation imposes certain minimum constraints on the number of drill holes. Similar constraints apply to the issue of down-hole sampling patterns (see also Section 2.2.3).

Ideally, the characterization of spatial variability proceeds in stages (Yfantis and others 1987), beginning with systematic exploratory sampling on a close-order basis in one or more subfields of interest. Once the approximate spatial structure of the rock property of interest is estimated, that information is used to design a systematic sampling effort to cover the entire field of interest. A triangular grid may be most efficient for site characterization under many circumstances and such a grid may give the most reliable estimate of the spatial structure. McBratney and Webster (1983) also support the use of a triangular grid, unless the spatial structure is anisotropic, in which case the use of a rectangular grid oriented with long intervals aligned in the direction of least rapid variation is recommended. The practice of focusing sampling efforts across geologic structure has been standard in the mining industry for many years.

The scoping studies referenced in Section 2.1.3, provide a first-pass evaluation of the spatial structure that may be expected at Yucca Mountain (additional discussion of evaluation methods is presented in Section 3.5 of this Study Plan). This work has been conducted over a significant period, and understanding of spatial correlation structure in volcanic tuffs has evolved over this time. Some preliminary data for porosity, a major "framework" rock property, relevant to the spacing of drill holes at Yucca Mountain are summarized in Table 2.2. No information is available regarding horizontal anisotropy because of the small number of surface transects and the exposure-controlled lack of diversity in the orientation of those sample grids. Anisotropy in the vertical plane is obviously rather strongly developed, if variable by unit, as indicated by the ratio of vertical range to horizontal range for similar units.

Table 2.2 Estimates of Spatial Correlation for Porosity in Tuffs at Yucca Mountain. Sources of information: Istok and others, 1991, Rautman, 1991; Rautman and others, 1991; Rautman and Flint, 1992

Unit Investigated	Correlation Range
Horizontal Correlation	
Tiva Canyon: upper cliff unit shardy base unit	< 500 ft (150 m) 100 ft (30 m)
Topopah Spring: caprock unit	700 ft (200 m)
Tuffs of Calico Hills (zeolitic)	3,000 ft (900 m)
Vertical Correlation	
Tiva Canyon (welded)	80 ft (24 m)

Table 2.2 Estimates of Spatial Correlation for Porosity in Tuffs at Yucca Mountain. Sources of information: Istok and others, 1991, Rautman, 1991; Rautman and others, 1991; Rautman and Flint, 1992

Unit Investigated	Correlation Range
Paintbrush nonwelded	30 ft (10 m)
Topopah Spring (welded)	200 ft (60 m)
Tuffs of Calico Hills (zeolitic)	200 ft (60 m)

Application of sampling theory is, of course, always constrained by practical details. Regular grids invariably are thrown askew by logistical considerations such as inaccessible topography or recalcitrant landowners. Exploratory sampling may indicate that spatial variability is greater than initially suspected, requiring more detailed sampling. Certain sampling locations may be fixed by preexisting or externally determined considerations. In the present instance of Yucca Mountain, there is an additional perceived need to limit the number of penetrations of the site to the extent practical and to restrict penetrations to locations compatible with preliminary underground facilities design. It is uncertain what, if any, bias is introduced into the resulting data by these departures from a completely regular grid. The potential for bias will be addressed through the statistical (geostatistical) evaluation. Additionally, the iterative nature of the Systematic Drilling Program (see Figure 2.2) will allow actions to correct any identified biases during the course of the drilling activities.

The approach of the *integrated* drilling program, of which the Systematic Drilling Program is only a part, is to provide holes located on a semi-regular, rectangular grid (Figure 2.1) covering the entire area of interest. Merging of hole locations for the Systematic Drilling Program with hole locations fixed by other requirements (principally holes to be drilled by other studies for specific purposes) cause deviations from regularity. Additional irregularities result from logistical constraints, principally surface topography and the need to drill holes within proposed pillar locations in the underground facilities. These requirements combined with the results of scoping studies (Section 2.1.3; Table 2.2) have resulted in changes from the preliminary pattern shown in SCP Figure 8.3.1.4-11. All drill hole locations referred to in this Study Plan are preliminary and are subject to change as the site characterization program progresses.

Initial coverage of the entire site is at a nominal spacing of 2,500 to 3,000 ft (750 to 900 m). Because of the nominal hole spacing, essentially all locations within the repository block will be within about 1,500 ft (500 m) of a sampled location. The rationale for each SD- hole is presented in Table 2.3. The first phase of drilling will only partially complete the grid intersections (Figure 2.1). This relatively wide-spaced drilling pattern will at least provide areal coverage of the entire repository block. Areal coverage is essential to identify major trends, or systematic changes, in rock properties across the repository region. An additional aspect to areal coverage is the need, in an engineering-geology project such as the Yucca Mountain Project, to locate several drill holes within a given fault block to facilitate proper geometric modeling of tilted and offset stratigraphic units. Sufficient control on subsurface geometry may assist in identifying potential fault offsets that are not obvious in higher stratigraphic levels at the present ground surface.

Table 2.3 Rationale for Proposed Locations of SD Drill Holes

Drill Hole	Brief Rationale
SD-1	Half-grid location, just outside perimeter drift; located to constrain dip of repository horizon (TSw2); proximity to holes UZ-4, -5
SD-2	Half-grid location modified by topography, drift configuration, proximity to holes UZ-14, WT-9
SD-3	Grid location modified by topography, drift configuration
SD-4	Grid location modified by topography, drift configuration
SD-5	Grid location modified by topography, drift configuration
SD-6	Grid location modified by topography, drift configuration, proximity to holes WT8, H-7
SD-7	Half-grid location modified by topography, drift configuration; proximity to holes UZ-2, -3
SD-8	Grid location modified by topography, drift configuration
SD-9	Half-grid location modified by topography, drift configuration adjusted to complement drill holes ES-1, 2; MPBH-1, 2
SD-10	Half-grid location modified by topography, drift configuration; adjacent to UZ-9 complex of 3 holes and hole UZ-7
SD-11	Half-grid location modified by topography, drift configuration; adjacent to UZ-9 complex of 3 holes and hole UZ-7
SD-12	Grid location modified by topography, drift configuration

The known emplacement mechanisms of the Yucca Mountain tuff sequences suggest that anisotropy may well exist. If so, the major axes of the anisotropy ellipse most likely will be related to the location of the source caldera and transport direction of the erupted ash flows. The Paintbrush tuffs at the site were derived from the Claim Canyon caldera segment and/or the Timber Mountain/Oasis Valley caldera complex, located almost directly north of the repository block (Carr, 1988). The semi-regular, rectangular grid with axes oriented north-south and east-west proposed for the integrated drilling program is a compromise between the need for areal coverage and the anticipated orientation of anisotropy (Figure 2.1). The rectangular nature of the grid is amenable to modification and infill drilling, if necessary, to describe lateral anisotropy. The likelihood of anisotropy at Yucca Mountain related to transport direction of the major tuff units argues against the use of a triangular grid.

Additional holes in the integrated drilling program (Table 2.1; Figure 1.3) are planned at spacings closer than approximately 3,000 ft (900 m) in order to provide geostatistical detail at short separations. Some of these holes are spaced as closely as 100 ft (30 m) apart. Because of the expense and time involved in drilling, all holes of the Systematic Drilling Program are integrated with drill holes planned by other site characterization studies (Table 2.1) in an effort to provide adequate geostatistical detail without creating unneeded penetrations of the site. Holes from other

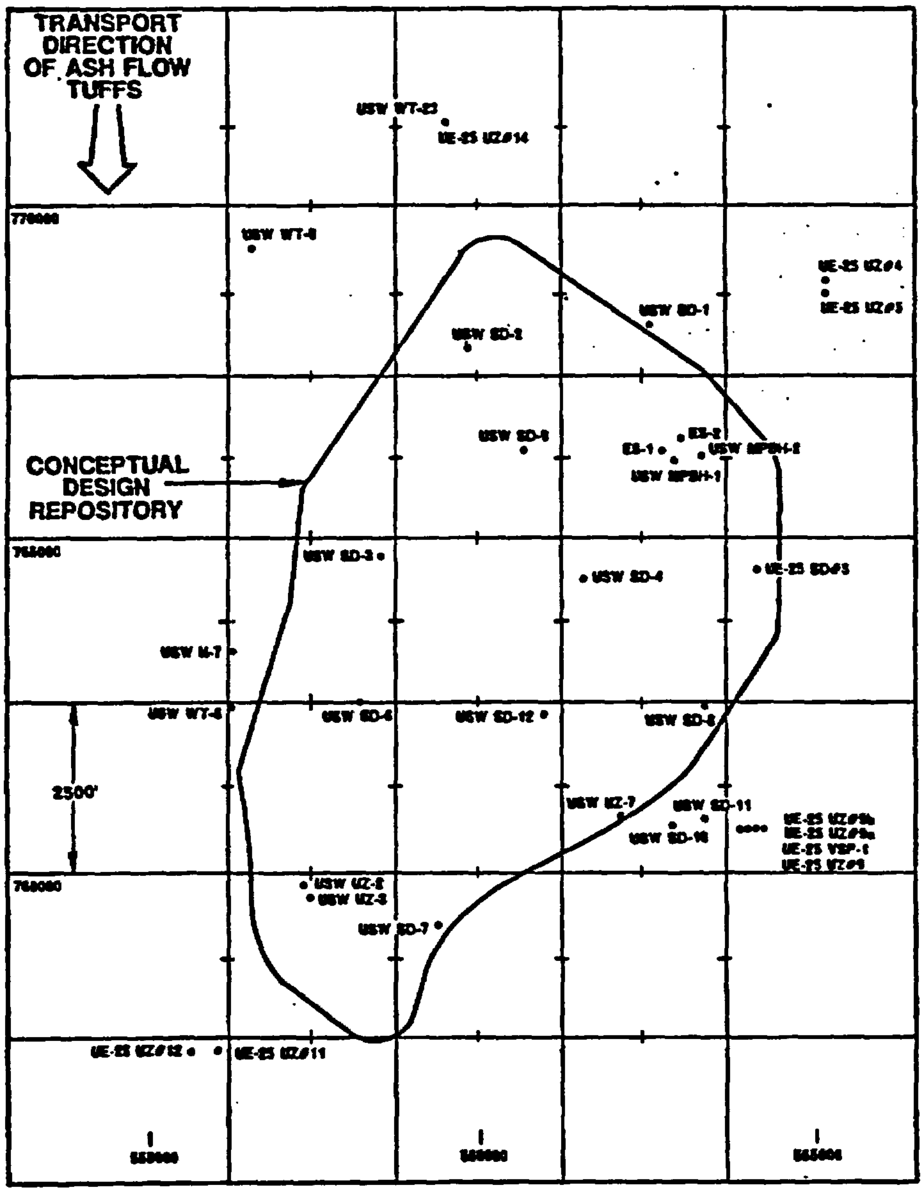

Figure 2.1 Sketch map of the repository block showing proposed hole locations for the integrated drilling program and the underlying, conceptual, systematic grid the program is attempting to implement. Six-digit numbered tick-marks are Nevada State Plane Coordinate System in feet.

drilling programs are particularly important with regard to the close-spaced holes. For example, the UZ-9 complex (Study 8.3.1.2.2.3, Unsaturated Zone Percolation) requires very closely spaced holes for cross-hole pneumatic (gas-tracer) testing. By locating a few SD- holes nearby, the quantity of data representing short separation distances can be expanded greatly. Data from these closely spaced holes plus information from the underground workings of the Exploratory Studies Facility should allow adequate determination of the short-range spatial structure of the rock mass forming the repository block. Understanding the short-range spatial continuity of barriers or conduits for ground water flow may be of particular importance to assessing the performance of the Yucca Mountain site.

Originally, the 2,500-3,000 ft hole spacing was intended to be within the range of correlation, based upon porosity data available from the tuffs of Calico Hills (see Table 2.2; Rautman, 1991, which reports data originally collected in early 1987). However, more recently, additional sampling (Rautman and others, 1991; Rautman and Flint, 1992) now suggests that the general range of correlation for matrix rock properties such as porosity may be an order of magnitude less than originally expected. Rautman and Flint suggest that the larger horizontal correlation distances reported for the tuffs of Calico Hills may reflect the more geographically widespread homogeneous environment beneath a stagnant water table that formed the zeolitic alteration characteristic of the sampled rocks. The "typical" volcanic environment sampled more recently appears to be more variable. Additionally, the correlation distance for rock properties such as permeability, may be less than that for porosity (Rautman, 1991). Because it seems unlikely that surface-based drilling can be conducted on the scale necessary to completely define spatial continuity patterns, additional sampling activities will be conducted on close spacings within the long lateral drifts of the Exploratory Studies Facility (see section 2.2.4).

2.2.3 Location and Number of Down-Hole Samples

The number of samples to be taken down any particular drill hole will necessarily be a composite determination developed by the interaction of the various studies that require samples from the core to be acquired by this study (Table 1.1). Samples are actually allocated to each requesting study by the Sample Overview Committee via the process schematically outlined in Section 2.5.3. Any discussion in this Study Plan must be viewed in light of these ongoing and drill-hole specific negotiations among interested Project participants.

Some general remarks are possible regarding plans for initial down-hole sampling for the specific laboratory rock properties to be measured by this study. Rautman and Flint (1992) have shown that vertical sample spacings on outcrop of approximately one sample every 5 ft (1.5 m) is adequate to reveal a large amount of detail regarding the distribution of the physical properties under consideration. Accordingly, initial sampling for the laboratory testing described in Section 3.4 of this Study Plan will be proposed at this frequency. For a "nominal" drill hole depth of 2,000 ft (600 m), this sample spacing implies approximately 400 samples per drill hole. The exact number of samples will vary as the proposed drill holes range in depth from 1,700 to 3,000 ft (500 to 900 m). In keeping with the systematic philosophy of this study, samples will be proposed at regular intervals in an effort to avoid introducing systematic bias into the properties thus measured. Obviously, it is impossible to avoid bias completely in dealing with real-world conditions, such as completely unconsolidated materials that physically cannot be sampled. However, systematic sampling will help avoid overt bias, and various approaches exist that will help evaluate the existence of bias. For example, geophysical logs (Section 3.3) may suggest that the density of rock in an unsampled, poor recovery interval is less than for adjacent sampled intervals, thus at least alerting the analyst to the potential for bias.

The data of Rautman and Flint (1992) also indicate that there are intervals wherein properties are changing sufficiently rapidly (their Figure 3), that more closely spaced sampling may be indicated. Also, the correlation distances reported by these authors for other intervals are large enough that the sampling requirements outlined above may be excessive, and fewer samples may be required for adequate characterization. Because the exact applicability of outcrop sampling information to subsurface materials is not known, this study will evaluate information from the first one or two deep drill holes and modify the proposed sampling scheme accordingly. Evaluation methods are discussed in Section 3.5. The feedback mechanism for changing the sampling pattern is discussed in Sections 2.5 and 3.0.

2.2.4 Location and Number of Samples from the Exploratory Studies Facility

Plans for the location and number of samples from the Exploratory Studies Facility are somewhat less well developed than for the surface drilling portion of this study. This condition is an artifact of the more limited and more constrained access for collecting the samples (there are only two main test levels proposed in the Exploratory Studies Facility), and of the fact that the ESF sampling is intended to supplement the development of spatial continuity patterns using drill hole data (where there are no such stratigraphic limitations).

The ultimate extent of underground sampling in the ESF workings (and associated testing activities, see Section 3.4) will be determined by the evaluation of data, both from scoping studies and more importantly from the surface drill holes (see Section 3.5.3). Locations of samples obviously will be constrained to the final workings of the Exploratory Studies Facility. However, an appropriate subset of workings with differing orientations will be selected for systematic sampling once ESF construction is underway. Samples will be collected from the ribs using a portable core drill or by collecting a large hand specimen and subcoring an appropriate sample for testing in the laboratory.

Preliminary indications of (stratigraphically) horizontal spatial correlation distances in the welded and nonwelded (but not zeolitized) tuffs at Yucca Mountain (Table 2.2) suggest that sample intervals on the order of 10 to 50 ft (3 to 15 m) may be required to resolve the close-order aspects of *horizontal* spatial patterns with a total range of 350-500 ft (100-150 m). These horizontal sample spacings are obviously not possible with surface-based sampling. Samples will be collected at regular intervals, with allowance for locations rendered inaccessible by installation of mine support equipment or facilities. If only the main northeast-southwest drifts and one complete crosscut of the repository area are considered, a minimum of 18,000 ft (5,500 m) of drift would be available for sampling on each of two test levels. At 50-ft (15 m) increments, 360 samples could be collected from the Topopah Spring repository level and an additional 360 samples from the Calico Hills test level. At 10-ft (3 m) spacing, the number of samples swells to 1,800 on each level. This level of detail should provide for excellent resolution of spatial continuity patterns *in these two units*. In practice, samples clustered at shorter spacings in several distributed areas probably will be collected in preference to two long one-dimensional profiles along the main drifts. This practice would reduce the total number of samples to a more manageable number, while providing the same spatial resolution (closest sample spacing).

2.3 Study Plan Alternatives

There are no alternatives to obtaining information from the site itself for site characterization. The Systematic Drilling Program Activity of this study is essentially the only SCP study that will provide significant quantities of information from deep within the repository block, other than studies conducted within the Exploratory Studies Facility. The UZ- prefix drill holes (Unsaturated Zone Percolation, Study 8.3.1.2.2.3) do provide similar information, generally in the immediate vicinity of the block. However, these UZ- holes are more properly regarded as part of the "feature-of-interest" aspect of site characterization, and those holes that are located within the outline of the proposed underground facilities (Figures 1.1, 1.3) may not be properly located to provide *systematic*, and unbiased, areally representative information in the repository block. Both sets of drill holes are intended to be considered collectively as part of the integrated site drilling effort.

Core and other drill-hole data from a variety of locations within the outline of the repository block are required to develop the more objective geologic framework: stratigraphic contacts, location of the repository horizon and faults, measurement of engineering stability of the rock mass, and so on. Physical rock samples are required for descriptions and laboratory testing to determine rock properties. Numerous studies have requested samples from the Systematic Drilling Program (Table 1.1). Although the general types of geologic features present, and the range and expected values of the various rock properties may be inferred from past experience in the Yucca Mountain region, it is impossible to make *location-specific* predictions without examining the site itself. Interpretation of indirect geologic methods such as surface geophysics, regional stratigraphy, or surface mapping yields results with sufficiently large uncertainties that they are inadequate for engineering design.

2.4 Study Plan Constraints

2.4.1 Potential Impacts on the Site

A first phase of twelve holes will be drilled as part of this study to various depths through the unsaturated zone; these holes will terminate below the static water table. Additional holes may be drilled as part of this study if geostatistical evaluation of the data obtained from the initial twelve holes indicates that more information is required for adequate site characterization.

Surface facilities associated with the drill holes include the drilling and ancillary equipment, power substations, and various trailers and temporary laboratory quarters. Actual surface disturbances include the drill pads and access roads. The drill holes themselves are the only subsurface disturbance. Holes will be drilled dry to avoid introducing large quantities of water and similar fluids into the subsurface. Other than geophysical logging of the completed drill holes, there are no known in-situ activities planned for the SD- series holes that would affect subsurface conditions. Because such in-situ testing or monitoring activities would be conducted by a study other than the Systematic Drilling Program, details of any testing or monitoring effects would be described in the appropriate study plan(s).

On a broader scale, the Systematic Drilling Program is only one of a number of drilling programs planned by the Yucca Mountain Site Characterization Project. Integration of drilling efforts, including evaluation of the effects of drilling on the site, is being conducted at the Project level. Section 8.4 of the SCP discusses potential impacts of site activities on the waste isolation characteristics of the site and presents analyses to demonstrate that such studies do not impact the site adversely. In particular, Section 8.4.3.2.5.2 discusses the effects of drilling on the site. Section 8.4.3.2.5.1 discusses the effects of surface construction activities, including those related to drilling.

2.4.2 Logistical Limitations

The Systematic Drilling Program is constrained principally by the logistics of drilling. Drilling at the Nevada Test Site is expensive, and completion of individual drill holes requires a substantial length of time (anticipated to be several months; see Sections 2.4.4 and 5.1.1). Furthermore, not all geographic locations on Yucca Mountain are amenable to selection as a drill site. Surface topography (Figure 1.3) constrains the actual location, and in some cases, the general spacing of drill holes as well.

Access and location constraints for the initial holes described in this Study Plan are not severe. In general, drill holes are located on ridge crests or near the bottoms of washes. Steep side-hill locations are avoided. Although the holes proposed in the report are located to avoid access across steep slopes, the sparseness of the drilling pattern allows an acceptable variety of alternate locations that meet the spacing requirements. Closely spaced holes are located in regions where surface topography is not a problem.

A somewhat more restrictive logistical constraint on the location of holes for the Systematic Drilling Program is the requirement contained in 10 CFR 60.10(d)(3) that such boreholes be located "to the extent practical" in unexcavated pillar areas of the underground facility. This has been accomplished by proposing that most SD- holes be drilled within pillars as shown on design drawings being developed for advanced conceptual design (Figure 1.3). In practice, final engineering design of the repository will be worked around the actual "as-built" subsurface locations of the drill holes, based upon down-hole deviation surveys (see Section 3.3).

Another logistical limitation that may affect the results of this study is the general inability of the drilling equipment anticipated for use by the Project (see also Section 3.1) to drill core holes at an angle other than vertical. Many of the structural features (fault, joints) to be described by this study are expected to occur at near-vertical angles. Such high-angle features are best intersected by surface-based drilling that is angled across the anticipated dip direction. On a Project basis, however (as opposed to for this study only), this logistical restriction is not expected to limit the quality of the data unduly. Other studies will conduct extensive mapping of structural features in the near-horizontal drifts of the Exploratory Studies Facility (Study 8.3.1.4.4.2, Characterization of Structural Features within the Site Area, Activity 8.3.1.4.2.2.4). The ESF drifts will be oriented almost ideally to describe high-angle structural discontinuities, particularly those that affect the actual repository horizon. Additionally, Study 8.3.1.4.2.2.4 (Characterization of Yucca Mountain Percolation in the Unsaturated Zone - ESF Study) contains an activity (Activity 8.3.1.2.2.4.4, Radial Borehole Tests) that will drill several near-horizontal drill holes from the underground ESF workings. These boreholes will also provide significant information on high-angle structural features within the immediate repository units.

2.4.3 Analytical Limitations

Most of the principal properties to be obtained directly by the Systematic Drilling program are descriptive and generally qualitative in nature, and they are acquired by geologic logging of the drill core. As such, the concept of "analytical limitations" is not particularly relevant, although there are a number of procedural limitations that relate to operation of the Project Sample Management Facility. For instance, geologists logging core in the custody of the Sample Management Facility are prohibited from performing standard logging activities such as scratching a mineral to determine its hardness or applying a drop of hydrochloric acid to identify calcite from dolomite or fluorite. Conducting such trivial and accepted geologic "tests" would require a formal specimen request, action by the Sample Overview Committee, and permanent removal of the designated core specimen from the core box with the result that no other investigator would ever see that piece of core without special arrangements. Although there may be valid arguments in favor of such restrictions, the effect of those procedural restrictions is to limit the ability of the geologist to perform his work in an timely and effective manner.

In any event, descriptions of the core are dependent upon the skill and experience of the geologist performing the examination. Stratigraphic unit identifications inevitably are geologic interpretations, and many of the contacts described at Yucca Mountain are gradational. Units may be encountered in the subsurface that are not exposed at the surface, and the investigator may be unfamiliar with these rock types. A significant body of knowledge regarding the stratigraphy of the Yucca Mountain site does exist, and the personnel involved in this study are anticipated to be experienced geologists. Accordingly, the descriptive information to be obtained by this study is expected to meet accepted geologic standards (see also Section 3.7).

Some general observations are relevant with respect to the analytical limitations involved in measuring the more quantitative material properties that will be determined on core samples. The integrated drilling program, of which the Systematic Drilling Program is only a part, is intended to describe a natural rock mass. Rock is, by its very nature, spatially variable. Mechanical limitations of the testing equipment to be used require relatively small physical specimens; many tests will use specimens of a few cubic centimeters to a few hundreds of cubic centimeters at most. Testing of such small samples will tend to increase the observed variability of any particular rock property. The precision of most laboratory tests proposed undoubtedly far exceeds the accuracy of those measurements in representing the effective property of any geologically significant volume of rock. Techniques exist to identify and quantify this small-scale variability; some of these methods are discussed in Section 3.5 of this Study Plan. Nevertheless, the natural complexity and multi-scale heterogeneity of a geologic environment must be considered when evaluating the analytical limitations of laboratory methods. Adequate sampling at small spatial separations is essential for adequate quantification of such small-scale variability.

The issue of adequate sampling at small spatial separations probably applies only to horizontal sampling as related to the spacing of individual drill holes. Down-hole samples can be obtained practically as close together as desired within reason. Limitations on total numbers of drill holes and horizontal drill hole spacings point out the necessity of horizontal sampling within the lateral drifts of the Exploratory Studies Facility.

The laboratory determinations of rock properties that will be conducted directly under this study (see Section 3.4) all involve standard tests. Analytical methods to support these determinations are considered adequate, and no extraordinary considerations are involved. The accuracy and precision of specific proposed tests are discussed in Section 3.7, and the test methodologies are described in Sections 3.4.1 and 3.4.2. The caveat regarding block-scale properties discussed in the immediately preceding paragraph applies to these rock property determinations. Discussion of the analytical limitations involved in measurement of specific rock properties to be measured by other SCP studies on samples obtained by this study can be found in the study plans for the studies actually conducting those measurements.

2.4.4 Time Constraints

A tentative, schematic schedule of work activities and reports is presented in Section 5 of this Study Plan. The schedule indicates that the 12 drill holes proposed for this study (plus holes drilled for other SCP programs that will provide additional geostatistical information) could be completed some 60 months after the initiation of drilling. This schedule, although preliminary and somewhat conceptual, will provide adequate time to complete the geostatistical evaluation and rock properties modeling of data from the Systematic Drilling Program for use in the license application. Information from the earlier-drilled holes will be available for use in advanced conceptual design. Because each drill hole will be reported independently following completion, design and performance activities may be based upon the data extant as of any arbitrary cutoff date. Obviously, design specifications predicated upon an unreasonably limited suite of data may need to be revised as more data are acquired. It should be noted that the drilling schedule is particularly critical because of the large number of studies that depend upon samples from the drilling effort (Table 1.1). Delay of the Systematic Drilling Program will delay rock-property testing programs, which in turn, will delay performance assessment and design analyses that require rock-properties data.

The current Project drilling schedule using multiple dual-wall, reverse-circulation core rigs and an average, best-guess estimate of the time required to drill each hole provides adequate time for the completion of this study prior to the license application. However, should the geostatistical evaluation indicate that current estimates of horizontal spatial correlation are too high and that closer drill hole spacing is required for adequate characterization, the time available for an expanded program of in-fill drilling may be inadequate. Also, the Systematic Drilling Program (or other repository-focused drilling programs) may identify geologic features or conditions (possible examples: faults, perched water zones, etc.) that require specific, more detailed characterization, again requiring additional drill holes and tests. Should these circumstances occur, alternatives will be evaluated. Improved estimates of the schedule will become available once drilling starts, and experience is gained regarding actual penetration rates for the available drilling equipment and the actual lithologies encountered at Yucca Mountain. Conduct of the Project drilling effort should be viewed as an iterative activity, as described below in Sections 2.2.3, 2.5.1, 2.5.2, and 2.5.3 (see also Figure 2.2). Evaluation of the adequacy of the planned program will be conducted on an on-going basis (Section 3.5).

2.5 Interrelationships of this Study to Other SCP Studies

As introduced in Section 1.1 (above), this study is unique in its focus on a restricted geographic area, rather than on some particular physical process or phenomenon. Site characterization at Yucca Mountain is directed toward the understanding how certain physical processes affect a limited parcel of real estate: the proposed repository block and the controlled area to the limits of the accessible environment (Figure 1.1). Understanding these processes is critical to evaluating the potential performance of the site with respect to waste isolation. Some processes operate on a scale larger than the repository block, for example, regional ground water flow, and thus may require evaluation over that complete scale. Description of other processes may require specialized measurements or sophisticated equipment. Measurement of fracture mechanical properties such as resistance to shear movement might be an example. Still other processes may require "active" testing that may more safely be conducted outside the immediate repository region; large-scale hydrologic pump tests or injection tests to determine aquifer characteristics might illustrate this category. The unifying principle behind all of the various process-oriented studies is the application of the understanding developed to the potential repository site itself. Absent this, the Yucca Mountain Project is merely conducting interesting science, not site characterization.

The interrelationship of this study to other SCP studies, shown schematically in the logic diagram of Figure 2.2, is perhaps best understood by examining the next higher level setting in which this particular study has been placed. This Study 8.3.1.4.3.1 is part of SCP Investigation 8.3.1.4.3, which is entitled "Development of Three-Dimensional Models of Rock Characteristics at the Repository Site." The other study under this Investigation is purely a modeling activity; all data for Study 8.3.1.4.3.2, Three-Dimensional Rock Characteristics Models, is assumed to come from elsewhere in the site characterization program. The completed "three-dimensional models of rock characteristics at the repository site" are then used as input to performance assessment or design calculations of various types. Why, then, is a site-based characterization effort (a drilling program) intimately associated with an investigation described as development of ... models? The answer to the question is that understanding the physics of ground water movement or of rock deformation *in general* may be insufficient to provide the *site-specific* description required for prediction of future events and assessing the performance of a nuclear waste repository to be located at such-and-such geographic coordinates. The Systematic Acquisition of Site-Specific Subsurface Information Study is intended to provide this particular type of information completeness, while at the same time relying on other, more process-oriented studies to provide the context for that information.

Just as it is obvious that this study cannot, by itself, provide all the site information required for a license application, it is also clear that integration of the myriad of site characterization studies being conducted by the Department of Energy cannot be accomplished through this Study Plan. Many issues of integration among studies alluded to in this document must be addressed on an ongoing and evolving basis by other Project management structures.

2.5.1 Information Flow and Evaluation of Data Completeness

In conducting a characterization effort sufficient to develop a license application, the flow of information and/or materials cannot be a one-way street. Because the purpose of site data collection is to support design and performance modeling, some mechanism must exist to ensure that the aggregate of site data is sufficient for the task at hand. Preferably, this feedback mechanism operates in "real time," providing the opportunity to adjust site characterization efforts to accommodate new data and an evolving understanding of the site.

Because of its areal focus on "the site" and its close relationship to the modeling activities of the broader investigation, this study is uniquely situated to provide this sort of feedback mechanism. Although the ultimate evaluation of data completeness belongs to performance assessment and/or design activities discussed elsewhere in the SCP, a good preliminary assessment of data adequacy and the identification of gross discrepancies between existing collection strategies and the implications of the data themselves can be conducted as part of the statistical and geostatistical evaluation of data described in Section 3.5 of this Study Plan (below).

2.5.2 Physical Properties Sampling and Testing

Sections 1.2 and 1.3 (among others in this Study Plan) state that the Systematic Drilling Program Activity will provide physical sample materials for laboratory testing. Because of the broad scope of "laboratory testing" and the specialized nature of many of the tests required, it is most appropriate to delegate measurement of most of these laboratory properties to the appropriate process-oriented site characterization study. Thus, the majority of the studies listed in Table 1.1 and shown on the logic diagram of Figure 2.2 will request, receive, and test rock samples from the Systematic Drilling Program under the provisions of their own Study Plans and supporting documents. An understanding and acceptance of this philosophy is assumed throughout this study Plan. The return flow of feedback is also assumed and is shown in Figure 2.2 through the arrow labeled "Evaluation and Feedback." Discussion of the mechanical details of the required integration is provided in Section 2.5.3 immediately below.

In addition to the delegation of general laboratory testing to a number of process-oriented studies (Table 1.1), the investigation-level purpose of this study (i.e. the construction of three-dimensional rock characteristics models) requires that a certain amount of physical properties (rock characteristics) testing be conducted under the direct control of this study in order to ensure timeliness of testing, completeness of sampling and rapid feedback of the required information. This suite of rock properties is restricted to measurements that are believed to reflect quantitatively the geologic framework of the mountain (drawing on work of Rautman and Flint, 1992) and that are obtainable without particularly sophisticated equipment or testing techniques. The specific rock properties measurements conducted as part of this Study Plan are listed briefly in Section 1.2 and are described in detail in Section 3.4. To ensure compatibility of testing results, this study will make use of the same techniques and procedures developed by the process-oriented study with primary responsibility for the relevant rock properties.

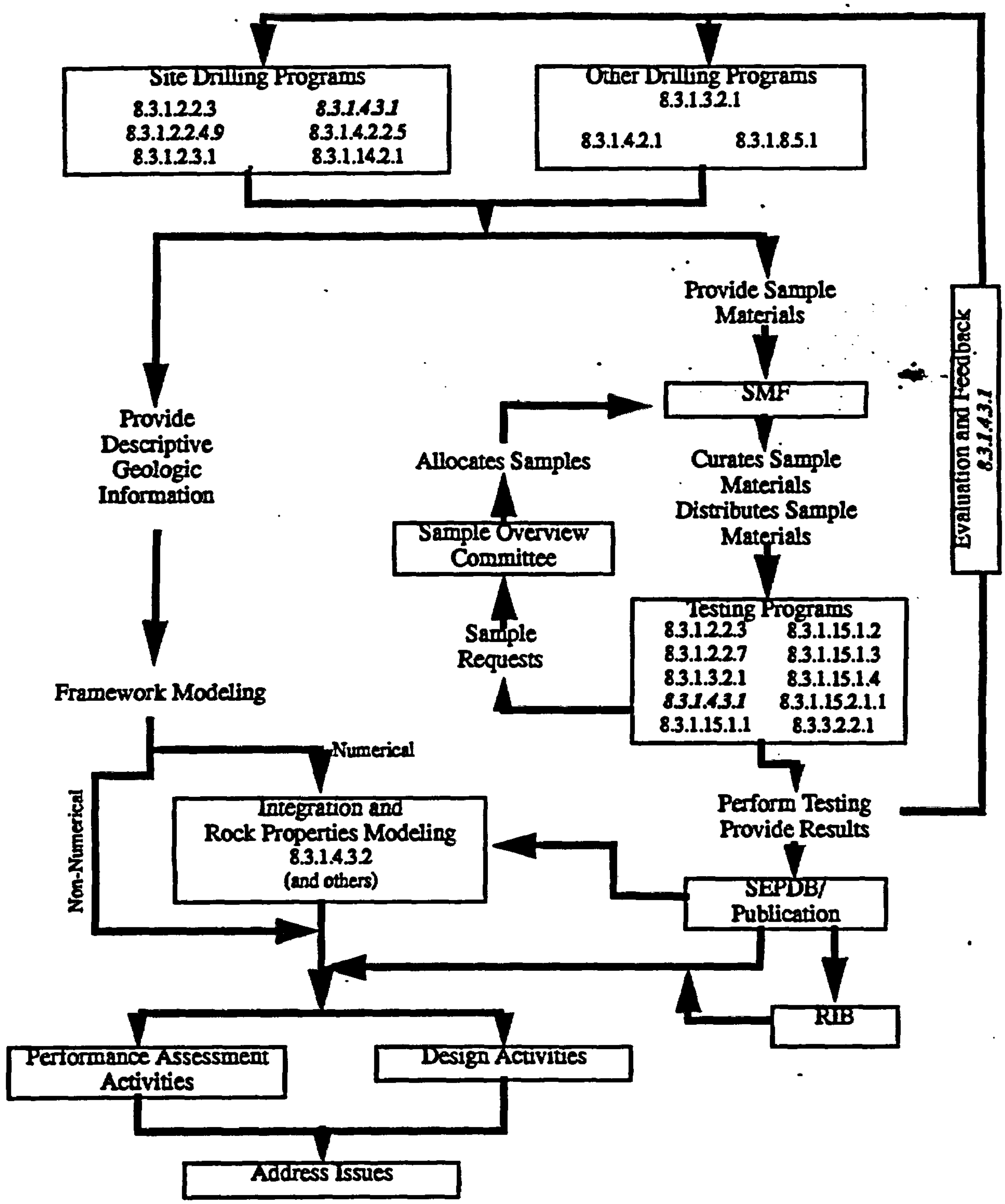

Figure 2.2 Logic diagram showing conceptual interrelationship of this study (***bold italics***) to other relevant SCP activities. Arrows suggest flow of information and/or sample materials. Identifiable "entities" are boxed; activities are unboxed. Diagram is necessarily incomplete if applied in detail outside of this study. Note that a single study can appear in more than one location if different functions are involved.

2.5.3 Mechanism of Integration

Maintaining integration of an effort as broad in scope as that represented conceptually in Figure 2.2 will not be easy. Other than informal agreements to cooperate between individual principal investigators, coordination of effort must be accomplished at the Project level in that the studies involved are conducted by investigators from different Project participants. Definition of such more formal coordination efforts are beyond the scope of this or of any other particular study. Nevertheless, some general discussion is possible in this Study Plan.

As indicated in Figure 2.2, the Project-level Sample Overview Committee plays an auxiliary, "counter-current" role in the generally unidirectional flow of information and sample materials. No drilling program (shown at the top of the logic diagram) fully "owns" or controls the core and other samples that it produces. Samples are a Project resource, and the means of allocation is through the Sample Overview Committee. Although the study conducting a particular drilling effort presumably has some priority when requesting sample materials, that priority is not absolute. Sample requests are processed by the Sample Overview Committee on a hole-by-hole basis, with certain sampling activities determined *a priori* in advance of drilling when required to preserve *in situ* conditions that would otherwise deteriorate. Other requests follow examination of the recovered core by a particular principal investigator. Given the sample-allocation authority of the committee (which is actually only a recommendation to the Project Manager), it would appear that the Sample Overview Committee serves as a principal mechanism for the integration of sampling, testing, and data-adequacy evaluation necessary for success of site characterization. Provisions for the return of testing results and the joint evaluation of sampling adequacy must be included in the allocation authority.

Coordination of the physical drilling and other drillsite activities will be accomplished through the test-planning packages and job packages, the inter-participant "contracts" that comprise the actual instructions to the Project architect/engineer, drillers, and other support organizations, such as the sample management facility (see also Sections 3.1 and 3.2). Because the test-planning package and job package are *ad hoc* documents developed essentially on a hole-by-hole basis with input from all interested Project participants, it is impossible for the Study to specify completely and in advance the requirements for Systematic Drilling Program drill holes.

Another mechanism for integrating separate activities across Project participants is the formal interface control process specified by the Project quality assurance program.

3.0 DESCRIPTION OF STUDY PLAN ACTIVITY

The Systematic Drilling Program described in the Site Characterization Plan consists of one activity. Although there is only one activity, description of the study is facilitated by considering a number of relatively distinct, separate tasks. Figure 3.1 portrays the general sequence of tasks related to the Systematic Drilling Program: (1) drill, (2) create geologic log, (3) conduct geophysical logging, (4) measure rock properties, and (5) evaluate data. Of these separate tasks, only the geologic logging (item 2), a small portion of the laboratory testing for rock properties (item 3), and evaluation of the data for drilling impacts (item 5) are actually conducted by investigators working under this study. Because the Systematic Drilling Program Activity is tied to the logistics of drilling, the next hole will be started soon after completion of the previous hole. Accordingly, more than one five-step sequence may be underway at any particular time. These five tasks are discussed at greater length below.

A Sandia National Laboratories experiment procedure, EP-0033, will direct the majority of field and laboratory work for this study. Some scoping activities will be covered under EP-0036 and potentially under other procedures. Experiment procedures are unique to Sandia among the various Yucca Mountain Project participants. They are distinct from study plans and provide the actual documentation for implementing a study. Experiment procedures may include technical procedures for actually conducting a study, or they may reference separate technical procedures. All technical procedures for this study that are internal to Sandia will be described or referenced in the experiment procedures and are listed in Table 3.1). Procedures for general (i.e., that *not* conducted under this study) laboratory rock-properties testing of samples from the Systematic Drilling Program are the responsibility of the studies conducting that testing. As discussed below in Section 3.4, technical procedures for rock properties testing conducted directly by this study will be adopted from the process-oriented study(ies) having "primary" responsibility for the testing in question.

Table 3.1 Technical Procedures for This Study

Procedure ID	Title	Date
EP-0033	Core Description and Logging	TBD
EP-0036	Field Research Program for Unsaturated Flow and Transport Experiments	TBD
TBD	Laboratory Determination of Rock Properties	TBD

3.1 Task 1, Drilling

Drilling of holes for the Systematic Drilling Program will provide the physical rock samples that are essential to both this study and to many other parts of the Yucca Mountain Project. This and all other site drilling will be conducted under policies and guidelines established by the Yucca Mountain Project. Discussion of factors determining such policies are found in Section 8.4 of the SCP.

The initial proposed holes for the Systematic Drilling Program are shown in Figure 1.3.

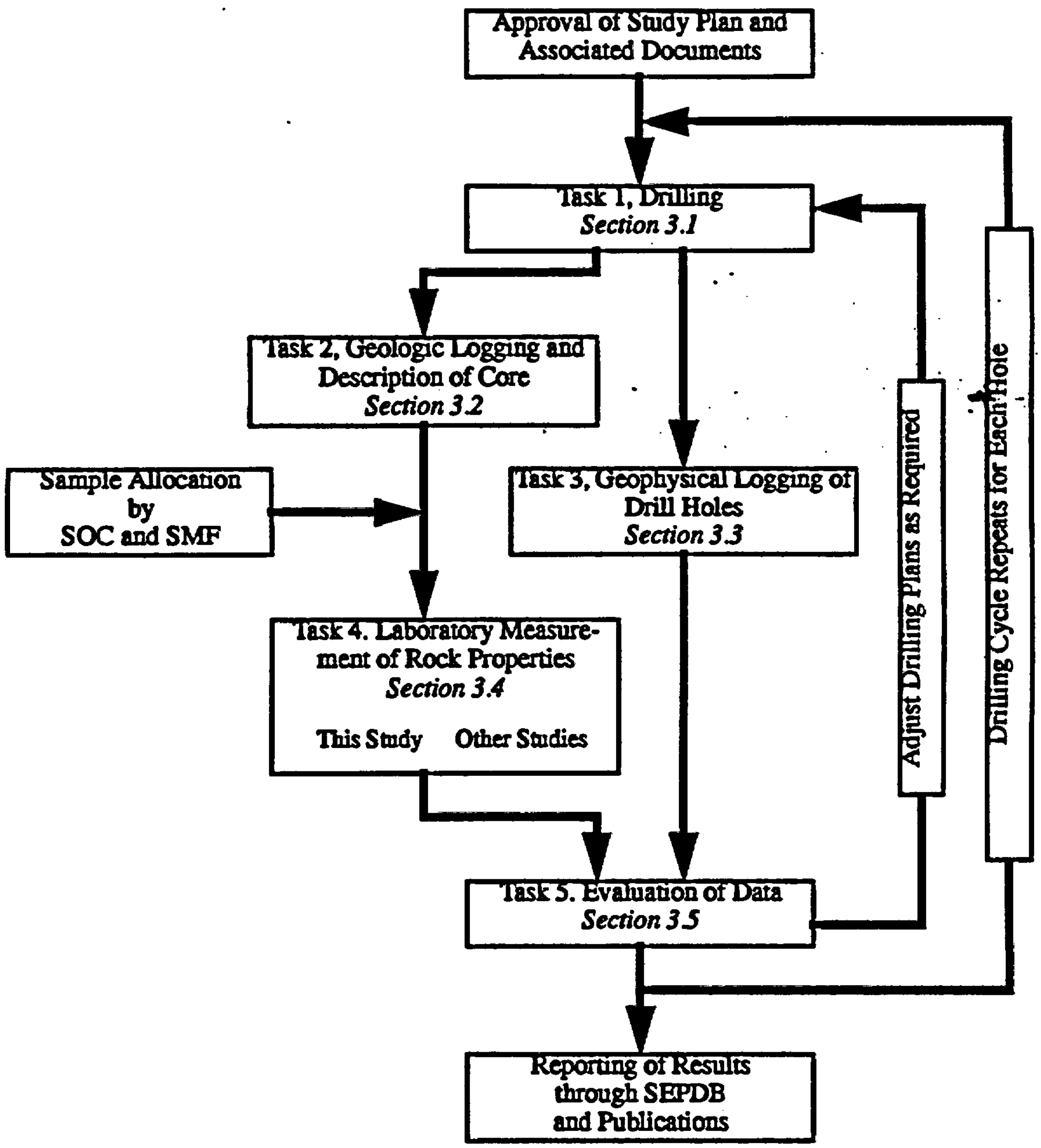

Figure 3.1 Schematic representation of the repeating sequence of five subactivities or tasks for the Systematic Drilling Program. Italic section numbers refer to sections of this Study Plan. Schedule for Task 1 depends upon the overall project drilling schedule for equipment availability.

The locations of these holes reflect consideration of logistical factors such as road access, topographic slope and pad area, preliminary estimates of spatial variability, expected locations of pillars in the underground facilities, and relationship to other proposed drill holes. Actual locations and other specifications will be finalized in formal job packages prior to the start of drilling.

Drilling operations will be conducted by a Nevada Test Site support contractor, Reynolds Electrical and Engineering Company (REECo). Specific operating procedures for drilling are the responsibility of REECo. Engineering specifications for drilling are developed by the Project Architect/Engineer, Raytheon Services Nevada in consultation with all interested Project participants (which includes this study). Because of the complex interplay -- and potential conflicts -- between requirements of the various studies that will use core from the Systematic Drilling Program or that will utilize the completed holes as *in situ* test facilities, the actual specifications for each hole will be finalized in formal job packages on a hole-by-hole basis developed by consultation among interested parties prior to the start of drilling (Section 2.5). Also, experience gained through early drilling at the site in all likelihood will result in modifications to the currently anticipated drilling criteria.

Preliminary requirements have been established and several prototype holes have been constructed off-site. Briefly, drilling will be done dry, without the introduction of water-based fluids into the hole in order to minimize alteration of *in situ* conditions or the hydrologic properties of the recovered core samples. Drilling will use a modified dual-wall reverse-circulation technique to obtain (nominally) continuous core. The minimum acceptable (usable) core size is NC or HQ wireline core: approximately two-and-a-half inches (6 cm) in diameter. Holes will be logged at appropriate points during and after the drilling process using various geophysical instruments as discussed in Section 3.3. The hole will be surveyed after completion to provide documentation of deviation from initial orientation.

3.2 Task 2, Geologic Logging and Description of Core

Geologic logging of drill core will provide the majority of the information to be gathered directly by the Systematic Drilling Program Study. This information will be used in one form or another by virtually all performance assessment and engineering design activities. Table 3.2 lists some key "parameters" to be obtained during geologic logging under this study. Observations made on drill core will be supplemented by use of various geophysical logs (Section 3.3), as deemed appropriate or necessary by the principal investigator.

Table 3.2 Parameters to be Obtained by Geologic Logging of Drill Core by the Systematic Drilling Program Activity

SCP "Parameter"	Description
Contacts: Geologic Units	depth, elevation, attitude, areal extent
Contacts: Thermal/Mechanical Units	depth, elevation, attitude, areal extent
Identification and thickness of rock units	

Table 3.2 Parameters to be Obtained by Geologic Logging of Drill Core by the Systematic Drilling Program Activity

SCP "Parameter"	Description
Lithologic descriptions, general	degree of welding; pumice size, type and abundance; lithic clast size, type and abundance; presence/absence of bedding
Lithologic descriptions, altered zones	type of alteration, location in drill hole
Key marker beds	depth, elevation, attitude, areal extent
Fault zones	location, approximate orientation (relative to core axis) and extent
Fractures	location, frequency, approximate orientation (relative to core axis)
Core recovery data	absolute quantity and percent core recovered
Rock Integrity information	RQD

Geologic logging of drill core from the Systematic Drilling Program is the principal focus of EP-0033. Logging will use a graphic logging technique adapted from standard mining industry practice, which typically is oriented toward the detailed description of a relatively limited volume of rock. Because a geologic repository is essentially a special-purpose mine, adaptation of this technique should provide much of the engineering data required and in a format suitable for design of the underground facilities.

Graphic logging essentially constructs a "one-dimensional" geologic map of the core. A scale of 1-inch-to-10-feet (1:120) is typically used, although zones of complex geology can be logged at any expanded scale desired in order to portray the features of interest. Colors, patterns, and symbols are used to indicate the location and orientation of faults, fractures, alteration phenomena, changes in rock type, and so on. Rock type and other relevant features are described at the appropriate depth location. A number of parallel columns are used to describe different types of features (fractures, rock type, intensity of welding, etc.). Drilling intervals (including missing intervals of no core recovery), feet of core recovered per interval, percent core recovery, and rock quality indicators such as RQD (Deere and others, 1967) are tabulated in adjacent columns.

Because core logging is, in effect, an exercise in mapping it is important that "exposures" of the core for logging purposes be as complete as possible. Intervals of core loss are inevitable and create gaps in the resulting information. Most commonly, core is lost in highly fractured or highly altered zones, and thus a certain amount of geologic information may be extracted simply from the existence of a missing interval. Additional information may be obtainable through integration of core logging with the results of geophysical logging of the drillhole.

There is an additional problem with "missing" core that may affect adequate geologic logging. Certain rock property measurements must be made on specimens that have been preserved in as close to *in situ* conditions as possible, given the physical realities of the drilling and core recovery process. Most of these measurements involve hydrologic variables that would be affected by the arid environment of southern Nevada, water content for example. Accordingly, some fraction of the core, variably estimated up to 30 or 40 percent of the total, will be removed from the intact core at the rig and preserved using an appropriate technique. Current plans under this study call for preservation of a small portion, approximately 2-3 inches (5 cm) every 5 ft (1.5 m), by "canning" a core fragment in steel "soup" cans. An additional roughly 1-ft (0.3 m) segment every 5 ft (1.5 m) will be preserved in transparent plastic (Lexan ™) cylinders and sealed appropriately. Other SCP studies (Table 1.1) may require additional preserved intervals, and the required preservation techniques may vary. Final specification of preservation practices to meet the requirements of all relevant studies will be made in the job packages that specify rig-site activities for each drill hole (see Section 2.5.3).

Because many site characterization studies will obtain core samples from the Systematic Drilling Program (Table 1.1), and because the final method of preservation cannot be known in advance, the protection and immediate removal of sensitive hydrologic specimens itself may create individually short, but cumulatively significant, intervals of core that would be, in effect, missing for some indeterminate period until the necessary laboratory procedures are completed. In contrast to core missing because of recovery problems caused by fracturing or alteration which in itself provides useful geologic information, the absence of this material is likely to reflect some highly arbitrary *a priori* sampling criterion. Clearly, geologic logs prepared under such artificially created conditions would be unacceptable for many purposes.

To alleviate the problems associated with preserved core, a practice will be adopted of videotaping the entire core run immediately upon removal from the core barrel. Immediately upon completion of filming, the requisite intervals will be preserved, and the remainder of the core marked for footage, orientation, etc. The core will then be boxed for transport and storage.[1] The entire core, including preserved intervals, will be available to this study, if required. Actual distribution of samples to other SCP studies will not take place until after the core has been logged and the existence of any critical features (contacts, faults, mineralization, etc.) within the preserved intervals noted and described.

3.3 Task 3, Geophysical Logging of Drill Holes

Geophysical logging of drill holes from the Systematic Drilling Program (and other Project drilling programs as well) will be conducted under Study 8.3.1.4.2.1, Characterization of Stratigraphic Units (Activity 8.3.1.4.2.1.3, Borehole Geophysical Surveys).[2] However, this study will maintain primary responsibility for specifying the primary logs and for integrating the information into the evaluation of drilling adequacy. A list of tentative geophysical logs is given in Table 3.3; these are the logs believed most relevant to the Systematic Drilling Program itself. Most of these log types are commercially available, but some may use experimental techniques. Details of the geophysical logging program are the responsibility of Study 8.3.1.4.2.1.3, and will

1. Note that rig-site operations are not conducted under this study, but are, instead, under the purview of the Project Sample Management Facility (see Section 2.5, Table 3.7), which operates under its own set of procedural specifications. Additional specifications for rig-site activities that are required by this (and other) Studies are contained in the hole-specific Job Package(s).

2. The Yucca Mountain Project is in the process of developing a Project-wide policy regarding a uniform geophysical logging program for drill holes at the site.

be described at length in the job packages related to each drill hole. The geophysical logs listed in the table are adequate for the purposes of the Systematic Drilling Program.

Task 3, geophysical logging is shown in Figure 3.1 as a quasi-independent activity in the sequence of tasks. Although ideally, geophysical logging need not be conducted until after drilling is completed, logistical considerations and specific borehole conditions may indicate that some or all geophysical logs be run at various times during drilling in various portions of the drill hole. In general it is not possible to predict the course of drilling, and decisions to run geophysical logs must be made in real time.

Table 3.3 Partial List of Potential Geophysical Logs
to be Run in Holes of the Systematic Drilling Program

Log Type	UZ	SZ
Gamma-ray (natural)	X	X
Compensated Density (gamma-gamma)	X	X
Compensated Neutron		X
Epithermal Neutron	X	X
Dual Induction Log (resistivity)		X
Spontaneous Potential (SP)		X
Sonic Log (seismic velocity)		X
Caliper	X	X
Video TV Camera	X	
Borehole Televiewer		X
Directional Survey (gyroscopic or photographic)	X	X
Note: some logs can be run only under certain hole conditions as indicated by "X" in UZ (unsaturated zone) or SZ (saturated zone columns.		

3.4 Task 4. Laboratory Measurement of Rock Properties

Only a limited suite of rock properties will be measured directly by this study; these material properties are listed in Table 3.4. Also presented in the table are the anticipated method of measurement and an estimate of the range of anticipated values. These framework properties selected are generally simply bulk properties of the rock mass, and they have been shown to be "independent" and quantitative measures of some of the more descriptive geologic parameters to be measured by this study (Table 3.2; see also Rautman and others, 1991). Additionally, these matrix properties are required for numerical modeling of hydrologic and mechanical behavior of the rock mass (Studies 8.3.1.2.2.3 and 8.3.1.15.1, for example). The interrelationship of this testing work with that conducted by other SCP studies is discussed in Section 2.5 of this Study Plan.

Table 3.4 List of Laboratory Rock Properties to be Measured by the Systematic Drilling Program (This Study)

Physical Property	Expected Range	Method[1]
Bulk Density	0.9 - 2.4 g/cm^3	liquid displacement/oven drying
Particle Density	2.0-2.7 g/cm^3	liquid displacement/oven drying
Porosity	1 -70%	liquid displacement/oven drying
Water Content, gravimetric and volumetric Saturation	0 - 1.0 g/g 0 - 1.0 cm^3/cm^3 0 - 100%	weight change on oven drying recalculation recalculation
Matrix Permeability, water saturated	10^{-9} - 10^{-5} cm/sec	constant head (for high flow samples) or constant flux methods (for low flow samples)

[1] Procedures selected to correspond to those in use by Activity 8.3.1.2.2.3.1, Matrix Hydrologic Properties Testing.

A compilation of all rock properties testing that is expected to be performed on core samples obtained by the Systematic Drilling Program is provided in Table 3.5.

Table 3.5 Rock Properties to be Measured on Core from the Systematic Drilling Program by All Project Participants (compiled from the SCP). Work by this Study Shown in Bold Italics (compare to Table 3.4.

Brief Description	Participant	SCP Study
Bulk Properties		
bulk density: dry, saturated	Sandia	***8.3.1.4.3.1***
		8.3.1.15.1.1
	USGS	8.3.1.2.2.3
particle density	Sandia	***8.3.1.4.3.1***
	USGS	8.3.1.2.2.3
grain density	Sandia	8.3.1.15.1.1
porosity	Sandia	***8.3.1.4.3.1***
		8.3.1.15.1.1
		8.3.1.2.2.3
Hydrologic Properties		

Table 3.5 Rock Properties to be Measured on Core from the Systematic Drilling Program by All Project Participants (compiled from the SCP). Work by this Study Shown in Bold Italics (compare to Table 3.4.

Brief Description	Participant	SCP Study
water content: gravimetric, volumetric	Sandia	***8.3.1.4.3.1***
	USGS	8.3.1.2.2.3
saturation		
water potential		
matric potential		
matrix permeability: water saturated		
	Sandia	***8.3.1.4.3.1***
		8.3.3.2.2.1
matrix permeability: gas saturated	USGS	8.3.1.2.2.3
relative permeability		
moisture retention relations		
Thermal Properties		
heat capacity	Sandia	8.3.1.15.1.1
thermal conductivity		
coefficient of linear thermal expansion		8.3.1.15.1.2
Mechanical Properties		
unconfined compressive strength	Sandia	8.3.1.15.1.3
Poisson's ratio		
Young's modulus		
P-wave (compressional) velocity		
S-wave (shear) velocity		
fracture normal stiffness		8.3.1.15.1.4
fracture shear stiffness		
fracture cohesion		
fracture coefficient of friction		
fracture surface roughness		
biaxial strain relief		8.3.1.15.2.1
Geochemical Properties		
mineralogy	LANL	8.3.1.3.2.1
unsaturated zone fluid chemistry	USGS	8.3.1.2.2.7

Table 3.5 indicates a common interest in several rock properties by this study and by Study 8.3.1.2.2.3 (Unsaturated Zone Percolation). This commonality is by design, and for some purposes, the two studies are in effect conducting a single drilling program. The principal difference is the issue of area versus process (see Sections 1.1 and 2.5). Study 8.3.1.2.2.3 is a process-oriented study, and is designed to investigate that process anywhere within the general site region. Study 8.3.1.4.3.1 (this Study Plan) is focused on the immediate repository block. Because the rock characteristics information from these two studies (in particular) will be used for virtually the same purposes, i.e., to construct numerical models of the geology for performance modeling, it is essential that the laboratory data obtained by the two studies be directly comparable. Accordingly, this study will adopt the identical laboratory techniques developed by the process-oriented Study 8.3.1.2.2.3. The results will be evaluated to ensure compatibility with the data obtained by

other Studies, as appropriate.

3.4.1 Methods, Bulk Properties

This study will obtain measurements of bulk properties for core samples, specifically porosity, bulk density, and "particle" or grain density. These bulk properties will be determined using Archimedes' principle of water displacement, followed by drying and measurement of the mass of water lost. This technique has been demonstrated to be simple, fast, and effective for tuff samples from Yucca Mountain (A. L. Flint, personal communication). Two particular experimental conditions have been identified that require discussion. First, full saturation of the sample has been shown to be important to the effective application of Archimedes' principle. For "tight" rocks such as welded tuff, replacement of entrapped air in small pores by a water-soluble gas, such as CO_2, prior to saturation has been demonstrated to be an effective solution to the problem of residual entrapped air. Additionally, some of the tuff units at Yucca Mountain contain zeolite and/or expandable clay minerals that contain water within their crystal structure. Standard sample drying practices, such as oven drying at 105° C, have been demonstrated to remove this structurally bound water, resulting in porosity and density values that are inaccurate (for instance, Martin and others, 1991). Bush and Jenkins (1970) have demonstrated that drying samples in a controlled-humidity, low-temperature chamber (45 percent relative humidity, 60° C) can alleviate many of these problems (see also Soeder and others, 1991).

3.4.2 Methods, Hydrologic Properties

This study will obtain measurements of several hydrologic properties, including the state variables of water content and saturation. These properties do not fit the principal intent of laboratory measurement of framework properties that assist in developing the three-dimensional rock characteristics model. In general, they are more properly part of a process-oriented study such as Study 8.3.1.2.2.3. However, the information is important to the overall Project, is easy to measure, and *must be obtained* (if it is going to be obtained) prior to any other testing. In addition to the state variables, measurements of specific permeability to water (which is equivalent to hydraulic conductivity) will be obtained by this study. Saturated matrix permeability is a framework property of vital interest to the rock characteristics modeling effort.

Gravimetric water content will be measured from the initial and "dried" weights of a core sample that has been preserved at the drill site to prevent evaporation of *in situ* moisture. Volumetric water content and saturation are recomputed from this basic data adjusting for bulk density and porosity of the rock. Drying of the sample to prevent the undesired loss of structurally bound water contained in zeolites and clay minerals is an issue similar to that discussed in Section 3.4.1 (above), and will be dealt with in similar manner.

Matrix permeability will be measured assuming Darcy flow using standard API (American Petroleum Institute) single-phase techniques in accordance with methods adopted by process-oriented Study 8.3.1.2.2.3 (Unsaturated Zone Percolation). A constant head approach has been adopted for samples capable of sustaining relatively high flow rates, whereas a constant flux approach has been adopted for samples capable of sustaining lower rates of flow.

3.5 Task 5. Evaluation of Data

The objective of site characterization is to provide information for use in designing and assessing the performance of the potential repository at Yucca Mountain. It therefore follows that the final determination of information adequacy is the purview of these activities. Nevertheless, such a final determination is far removed from the field operations of this study both in time and in logic. More immediate indicators of likely data adequacy or obvious inadequacy are required to guide these activities.

A problem relevant to the conduct of the Systematic Drilling Program itself is the determination of sample spacing, and thus the number of samples. The number and preliminary spacing of both drill holes and down-hole samples is discussed in Section 2.2. Although the preliminary decisions documented in these sections are based on the best available knowledge from scoping activities in the vicinity of the site, the information obtained from the subsurface of Yucca Mountain may be quite different. It is therefore essential that data obtained from the drill holes be reported and evaluated on an on-going basis. In this manner, it may be possible to adjust the sampling and laboratory rock-properties programs to produce more valuable information. This feedback mechanism is illustrated in Figures 2.2 and 3.1

There are essentially two approaches to the preliminary evaluation of data adequacy to be conducted by this study (i.e., an evaluation not based on the results of performance assessment calculations). First, samples may be treated according to classical statistics as independent samples drawn from some underlying, statistically homogeneous population. In this case, the principal concern is likely to be with estimating population parameters, such as the mean and variance, with some desired degree of confidence. Alternatively, samples may be viewed according to geostatistics as representing a regionalized variable with definable spatial (autocorrelation) structure. Classical statistical treatment of spatial samples represents a limiting case for a regionalized variable, wherein the spatial continuity is of sufficiently small extent that it is beyond resolution by the sampling process at hand. Recall, however, that one of the basic premises of this study (see Section 2.1.2) is that the rock properties of interest at Yucca Mountain are spatially correlated. These two alternative methods of data evaluation are discussed at greater length in the following subsections.

3.5.1 Classical Statistical Approach

If rock samples are assumed to represent independent samples, it is possible to apply classical statistical techniques to make inferences about the expected (mean) value of the underlying population with some degree of certainty. Further assumptions are required regarding the distribution of values in the overall population; assumptions of normal or log-normal distributions are frequently used. These assumptions are almost always violated to some degree in dealing with geologic materials. However, for "relatively" normal populations, the sample size required to estimate the population parameters within some specified degree of confidence can be calculated to a first approximation using these techniques.

The classical equation for sample size is derived from the definition of the Student t-distribution, which may be rearranged as

$$n = \left(\frac{t_{(1-\alpha)} \times s}{\overline{X} - \mu}\right)^2$$

where s is an estimate of the standard deviation, $(\overline{X}-\mu)$ is the required limit on the deviation of the sample mean from the true population mean, and $t_{(1-\alpha)}$ is the Student t value for the desired confidence level, α, with n-1 degrees of freedom.

Use of the equation to determine n prior to conducting a sampling program assumes that there is a "good" estimate of the standard deviation. The mean must also be known sufficiently that a meaningful deviation $(\overline{X}-\mu)$ can be determined. Such estimates would necessarily come from some analogous other population or would need to be assumed. Because $t_{(1-\alpha)}$ depends on sample size for samples smaller than about 100, determining the actual sample size is essentially an iterative procedure. Table 3.6 represents an attempt to compute n for a hypothetical parameter having specified coefficients of variation and with a desired percentage deviation of the sample mean from the true population mean. Recall that the coefficient of variation is defined as the standard deviation divided by the mean. Thus porosity might be a property with a coefficient of variation equal to about 0.2, whereas saturated conductivity might have a coefficient of variation equal to 1 (Barnard and others, 1992). In application, the final test is to calculate the sample mean and standard deviation and to use those parameters to derive confidence limits on the equivalent population parameters. If the confidence limits are too broad to be acceptable, based on anticipated uses in performance assessment, then additional sampling is required. McBratney and Webster (1983, p. 177) report the widespread use of this method of sample-size determination in the soils literature.

Table 3.6 Approximate Numbers of Samples Required to Obtain Specified Deviation of Sample From True Mean for Various Coefficients of Variation

Coeff.Var.	n for $(\overline{X}-\mu)$=10%	n for $(\overline{X}-\mu)$=50%
0.1	7	1
0.2	18	3
0.5	100	7
1.0	384	18

An alternative approach to determining the required sample size is presented by Barnes (1988). Barnes assumes that for some purposes, the crucial information is not the expected, or mean, value of a variable. Rather, the point of an investigation may be to determine the extreme values of that particular variable with some specified degree of confidence. Extreme values may be associated, for example, with some mode of failure of the system under investigation. Barnes (based on a citation from Mood and others, 1974) goes on to state that for independent samples, the probability that a set of N samples contains a maximum value greater than or equal to the β percentile of the underlying distribution may be calculated as

$$Pr(max(Nsamples) \geq \beta percentile) = 1 - \beta^N .$$

This function is plotted in Figure 3.2 for several commonly used percentiles (0.90, 0.95, 0.99).

For example, to achieve a 95-percent probability that the maximum value sampled from some population equals or exceeds the 95-th percentile of the underlying distribution, 58 independent samples are required.

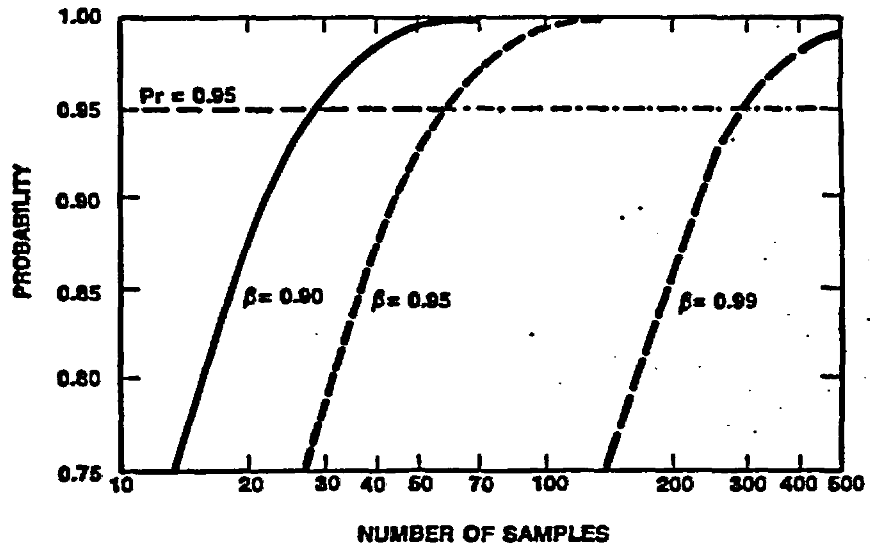

Figure 3.2 Graph showing the relationship between number of samples (N) and the probability that the maximum of N samples is equal to or greater than the β percentile of the underlying distribution (Barnes, 1988). The relationship is shown for $\beta = 0.90, 0.95,$ and 0.99.

The formula is independent of the underlying distribution shape, mean, and variance (Barnes, 1988, p. 479), and follows directly from probability theory. However, direct application of the technique requires that the samples be independent of one another. If the samples are spatially correlated, each sample value contains less information, with the result that the number of actual samples, N, must be replaced with an equivalent number of uncorrelated samples, Neq, thus

$$Pr(max(Nsamples) \geq \beta percentile) = 1 - \beta^{Neq},$$

where $Neq \leq N$. In other words, to achieve a desired level of confidence that extreme values have been sampled, it is likely that more samples will be required than indicated by classical statistics. In effect, each additional sample does not contain a "full" sample's worth of information. The exact amount by which the information content of each sample is reduced depends upon both the degree of spatial correlation and the specific geographic arrangement of the samples. Calculating the equivalent number of samples, Neq, using Barnes' approach requires a description of the degree of spatial correlation via geostatistics, as discussed in the following section.

3.5.2 Geostatistical Approach

In contrast with classical statistics, geostatistics begins with the assumption that the samples are not independent of one another. Rather, the assumption is that samples taken "close" together will, on average, "tend" to resemble each other whereas samples taken at greater separations will be less similar. Spatial location of individual samples is explicitly incorporated into geostatistical calculations. The degree and extent of spatial correlation is estimated (typically from the data themselves), and this spatial dependence is then used to improve the estimation of values at unsampled locations over what would otherwise be possible using classical statistics. Additionally, the uncertainty in these estimated or predicted values can be approximated, subject to various parametric assumptions of multi-Gaussian behavior. A somewhat modified approach to uncertainty analysis involves predicting the probability of exceeding some particular value at a location or locations of interest (see, for example, Journel, 1983). A side benefit of utilizing such spatial dependence is that observations taken close together carry some degree of duplicate information, thus offering the potential of reducing the number of samples required for estimation of expected values within a given region of interest (McBratney and Webster, 1983, p. 178).

The basic tool of geostatistics is the semivariogram (or more simply, the variogram), a plot of variability (expressed as one-half the average squared difference) between pairs of values as a function of the distance between those pairs of samples (Journel and Huijbregts, 1978; Clark, 1979; see Figure 3.3). If spatial correlation is present, the variability of pairs of samples collected close together will be relatively small, and this variability will progressively increase -- perhaps to a limiting value (the sill) approximately equal to the population variance -- as the separation distance between members of the pairs increases. This increasing variance with separation distance typically is moderately well behaved and can be represented by a number of specially developed mathematical functions or "theoretical" variogram models. A theoretical variogram model of a specified type is characterized by its parameters, the range, a, the sill, c, and the so-called nugget effect c_0; these are illustrated in Figure 3.3. The values of a rock property at unsampled locations may be estimated by creating a weighted average of the existing samples surrounding the unknown location, where the weights assigned to each known value are calculated as a spatial function of the theoretical variogram. This process of calculating the expected value of a particular rock property at an unsampled location is generally referred to as kriging. Geostatistical methodology may also be used to simulate a number of possible alternative values at unsampled locations, all of which are consistent with the known, sampled values and the observed spatial structure (Journel and Alabert, 1989). Such simulations may be input to Monte Carlo-style uncertainty analyses (Journel, 1989; Rautman and Treadway, 1991).

Figure 3.3 is an example of a variogram obtained from a set of porosity data collected from outcrops of the zeolitic tuffs of Calico Hills north of the repository site near Prow Pass (Rautman, 1991). The data represent data taken along a (stratigraphically) horizontal traverse, essentially along bedding. There is a pronounced increase in the average squared difference between pairs as the separation distance between members of each pair increases. For pairs separated by more than about 2,500-3000 ft, the variability appears to reach an erratic but definite plateau. The solid curve in Figure 3.3 represents a so-called spherical variogram model, which captures the essence of the observed data. Its mathematical formula would be used in estimating the values of porosity at unsampled locations and could be used in creating multiple simulations of porosity for use in stochastic groundwater models.

The portion of the variogram most important for estimation is near the origin because this

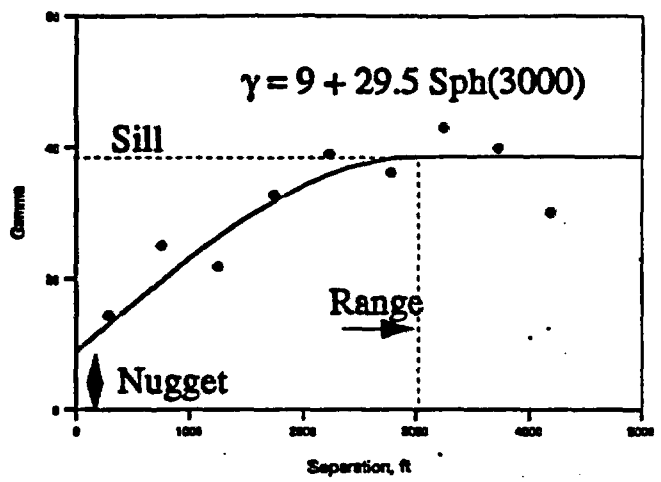

Figure 3.3 Variogram of horizontal porosity data from outcrop samples of zeolitic tuffs of Calico Hills taken north of Yucca Mountain near Prow Pass. From Rautman, 1991. Components of variogram model shown are referred to in text and are given in the form $\gamma = c_0 + c$ Model Type(a).

portion of the theoretical model is what influences most heavily the estimation of nearby unsampled locations. Although closely spaced samples may be obtained from along drill holes, there is no particular reason to expect that the spatial structure is the same in the vertical and horizontal directions. Table 2.2 summarizes some of the known information on correlation range and implied vertical-to-horizontal anisotropy ratios developed by scoping studies at Yucca Mountain. This information combined with the limitations on close drill hole spacings at the site indicate that closely spaced samples from the Exploratory Studies Facility will be essential in modeling short-range spatial dependencies and in modeling the site itself for performance assessment and design.

3.5.3 Evaluation of Data Adequacy

Investigators working under this study will apply various of the techniques described in this Section 3.5 to evaluate, in a preliminary manner, the adequacy of the data being collected by this study and by other studies as described in Section 2.5. Because the actual use of the data described by the Study Plan in performance assessment and design activities is the final determinant of "adequacy," the evaluation described in this section can only be indicative of adequacy or inadequacy. Note that the evaluation of data adequacy will be performed on an on-going and iterative basis (feedback loops in Figures 2.2 and 3.1). The results of early holes will be used to modify plans for later holes, if required to ensure data adequacy.

As Rautman and Flint (1992) have noted, it is not entirely clear what constitutes a population at Yucca Mountain for statistical purposes (see also Section 2.1.2). Rautman and others (1991) obtained information that suggests that the microstratigraphic units shown in Figure 1.2 may be the appropriate level of subdivision. Simple graphical displays (see Rautman and Flint, their Figure 3) of the framework properties measured by this study (Table 3.4), plotted as a function of drill hole depth and matched with the more descriptive geologic information obtained from core logging, will be used to help identify what may constitute a useful statistical population. For down-hole intervals that are relatively discrete from other intervals, application of techniques from classical statistics (Section 3.5.1) may yield good indications of data adequacy.

Other intervals, however, simply cannot be treated as statistically homogeneous populations. This is one of the underlying assumptions of this study as discussed in Section 2.1.2. Samples and laboratory measurements from these intervals will be evaluated using geostatistical techniques, such as the variogram analysis described in Section 3.5.2, to ensure that samples are being spaced closely enough to capture most of the spatial variability. The usefulness of variogram analysis is that the range of the variogram (a, see Figure 3.3) provides an estimate of the maximum intersample distance. The "optimal" intersample distance will be less, of course. The relative nugget effect, c_o, or apparent y-intercept of the variogram model, provides additional information on sample spacing. A large nugget relative to the overall sill, suggests that there is a great deal of unresolved spatial variability. Conversely, a well defined variogram model with a relatively small nugget effect suggests that overall variability is well modeled, especially if there are even a few pairs of samples at very short spacings that confirm the low-nugget model. Because the intent of initial sampling efforts for this study is to provide data on roughly a meter-scale vertically (about one sample per 1.5 m; Section 2.2.3), the results of the first one or two drill holes should provide strong evidence as to adequacy of these plans. Additional, if slightly more qualitative information, will be available at very short spacings from geophysical logs. Geophysical logs (Section 3.3) will also be used to evaluate the potential for bias being introduced in intervals that could not be sampled for one reason or another. Large residual variability, as indicated by a large nugget effect, on a less-than-meter scale probably cannot be addressed simply by routine sampling and testing. Should these types of variogram patterns be suggested by the data, other approaches, yet to be determined, will need to be investigated. Such variability probably would indicate a "process" type of issue, and investigators working under this study would need to coordinate a resolution with the appropriate process-oriented study, as discussed in Sections 1.1 and 2.5.

Evaluation of drill hole spacing adequacy will be performed using the same techniques described in the preceding paragraph. Horizontal variograms will be constructed for various stratigraphic increments. Large nugget effects observed in these analytic plots would suggest that drill holes are being spaced at intervals that are too large compared with the spatial variability of the rock properties of interest. Because the scoping data obtained to date (Section 2.2.2) suggests that this is, in fact, the case, data taken from the (largely) stratigraphically horizontal "exposure" of tuffs from Topopah Spring Member and Calico Hills unit in the Exploratory Studies Facility will be added to the evaluation data set. It then should be possible to define the range of spatial correlation using these additional samples.

3.5.4 Assessment of Laboratory Results Obtained by Different Laboratories

In general, this study will not be responsible for evaluating the measurements of rock properties obtained by different laboratories, since the majority of properties are determined by an appropriate process-oriented study. However, Table 3.5 does indicate that some properties are to be measured by more than one laboratory. Because use of these data in performance assessment and design activities requires a certain degree of compatibility for measurements of what, ostensibly, are the "same" material property, there is a potential for inter-laboratory differences to confound the issue. If the samples that are subjected to multiple-laboratory measurement are independent, there is an extensive body of statistical literature that can be used to assess the existence and extent of inter-lab variability. If, however, as is likely the case for geologic materials, the samples are not independent observations of the same statistical population, these classical techniques, such as analysis of variance, are likely to give misleading results.

This study proposes to address the issue of inter-laboratory variability, if appropriate, through the type of geostatistical analysis described in Section 3.5.2, above. If (for example) porosity values measured by one laboratory give essentially the same variogram model as samples tested by a different laboratory, or if the combination of two (laboratory) data sets forms essentially the same pattern as the sets do individually, then it appears likely that the laboratory results are essentially equivalent. Any differences in mean values observed in samples tested by various laboratories, which form the basis for classical statistical evaluations of inter-lab variability, presumably reflect real differences in the material tested by each lab. Such differences probably originate in the locations of the original samples.

3.6 Quality Assurance Requirements and the Experiment Procedure

The major portion of the activity in the study is quality affecting as indicated on the approved Quality Assurance Grading Report (QAGR) S1232221A. Planning and scoping activities are not considered non-quality affecting, but are of special programmatic importance as indicated on a separate QAGR (S1232221B). All work will be performed in accordance with the SNL Quality Assurance Program Description. Sandia Experiment Procedures will describe the operation and technical procedures required to fulfill the objectives of this Study Plan (Table 3.1).

3.7 Accuracy and Precision of Results

Much of the information obtained by this study is interpretive in nature. As such, the reliability of this information depends highly upon the experience of the principal investigator(s) and other scientific staff involved in the collection and analysis of the data. As discussed in Section 2.4.3, determination of stratigraphic contacts, particularly gradational ones, is subjective. In many cases, consistency of determination (a surrogate for precision?) is more important to the resolution of geologic problems than the correctness of a stratigraphic pick, especially when "correct" is ill-defined and indeterminate. Most such gradational intervals that would be subject to differing interpretations are of relatively small extent compared with the overall stratigraphic unit under consideration (compare the roughly 30-foot gradational base of the Tiva Canyon member compared with the 450-ft extent of the overall unit; Rautman and Flint, 1992). Most of the subjective and interpretive information to be obtained by this study is easily recognized as such. Experienced personnel are likely to note unusual uncertainties while describing core and to review geologic logs for consistency between drill holes (or with known outcrops).

Table 3.2 lists the main geologic and engineering parameters to be obtained directly by the Systematic Drilling Program. The principal quantitative measurements to be obtained are the thickness and depths within the hole of certain features of interest. Under optimal conditions such as 100-percent core recovery and intact (non-fractured) core, depth and thickness measurements are easily made to ±0.1 ft (a few cm). However, depth measurements are tied to the driller's measurement of hole depth at drilling breaks to recover core. These latter measurements are rarely accurate to within one foot (0.3 m), particularly in deep holes. Also, optimal core condition frequently do not exist. Core maybe be left at the bottom of a hole to be destroyed upon reentry or to be picked up with the next core run. Core may be lost (ground up) during drilling. Highly fractured intervals may not be reconstructible at the surface to the "intact" *in situ* dimensions for measurement. The accuracy of measurements obtainable under these conditions may only be to within 5 or 10 feet (2 or 3 m). These inherent limitations on the accuracy and precision of these quantitative measurements are judged acceptable except in intervals of severe core loss. In such instances, available core information will be combined with other information, such as geophysical logs, to arrive at the best possible depth measurement.

There are also limitations on the ability to determine the exact path of a borehole underground. Although holes for the Systematic Drilling Program will be surveyed using down-hole instrumentation, unique hole conditions may affect the survey results. In summary, it is probably possible to locate a given feature to within roughly 10 feet (3 m) of its true spatial position, with smaller errors nearer the topographic surface and larger errors at greater depths. Errors of this magnitude at repository depths (greater than 600 ft or 200 m by regulation) are on the order of 2 percent vertically and significantly less horizontally compared with repository dimensions of 2,000 to 10,000 ft (600-3,000 m). Quantitative requirements for spatial accuracy are difficult to determine, however SCP Table 8.3.2.2-5 specifies accuracies of 10 to 100 ft (3-30 m) for spatial type variables.

Other information, particularly the laboratory determinations of physical rock properties, is relatively objective and mechanistic by comparison with the interpretation of contacts between units and faults. The accuracy and precision of these data will depend principally upon the specifications for data acquisition and reduction outlined in the experiment procedure and technical procedures used to conduct the measurements. The precision of the bulk matrix properties listed in Table 3.4 is estimated at approximately 0.25 to 0.5 percent. Permeability measurements are probably precise to a factor of 2 to 5. The limits of any measurement in representing block-scale properties is discussed in Section 2.4.3.

It is useful to note that the "accuracy and precision" of all data obtained from drill hole samples is somewhat limited in terms of their absolute location in space by the sampling and measuring constraints discussed in the preceding paragraphs. Additionally, the uncertainties that arise in estimating rock properties at unsampled locations generally far outstrip the measurement uncertainty of laboratory testing. Various geostatistical and other techniques exist for assessing the impact on these characterization uncertainties on the results of performance calculations (see; for example, Journel, 1989; Rautman and Treadway, 1991). Discussion of this aspect of uncertainty assessment is far beyond the scope of this Study Plan.

3.8 Range of Expected Results

Because the majority of the parameters to be obtained by the Systematic Drilling Program are qualitative in nature, the concept of a "range" of values really does not apply in many instances. The data frequently are descriptive in a verbal sense. With respect to the more quantitative of the descriptive variables to be measured, depths and thicknesses are limited to the total depth of the drill holes, which are expected to range between about 2,000 and 2,600 feet (600-800 m). Core recovery is expected to range between zero and 100 percent; the mean core recovery of *all* information contained in the Project Site and Engineering Properties Data Base is roughly 80-85 percent. RQD values likewise range from zero to 100, and are essentially a percentage recovery of "good" core (not highly fractured and broken). [1]

The ranges of values expected for the laboratory rock property determinations to be measured by this study are given in Table 3.4. The ranges of values expected for other laboratory rock properties to be measured on core samples from the Systematic Drilling Program, but which are measured by other site characterization studies are tabulated in the study plans for the appropriate testing activities (see Table 3.5).

3.9 Equipment Requirements

With the exception of the drilling equipment needed to core without water-based fluids to 3,000-ft (900-m) depths, all equipment and support required for this study are standard. A list of equipment typically used for this type of geologic study is presented in Table 3.7. Laboratory equipment used in the measurement of the suite of rock properties to be measured by this study (Table 3.4) are also listed in Table 3.7. Technical equipment required will be described in more detail in the experiment procedure and any technical procedures use to implement this study.

Table 3.7 Illustrative Equipment List for the Systematic Drilling Program

Activity	Description of Equipment
Drilling[1]	Dual-wall, reverse-circulation core rig Drill pipe, bits, core barrels Standard drilling support tools Standard drilling support equipment (bulldozer, water trucks, pumps, air compressors, pipe racks, fishing tools, etc.)
Sampling[2]	Core boxes, core blocks, marking and labeling supplies, etc. Preservation materials (Lexan™ tubes and seals, cans and lids, wax, etc.) Rock saws, subcoring equipment, rock hammer Photographic equipment
Geologic Core Logging	Hand lens, binocular microscope, rock hammer, measuring tape, marking and labeling supplies, logging sheets, colored pencils, pens, etc. Photographic equipment

1. The Project has not collected RQD measurements in the past. Instead, a composite quantity known as CI or core index has been measured instead; the two quantities are not directly comparable.

Table 3.7 Illustrative Equipment List for the Systematic Drilling Program

Activity	Description of Equipment
Laboratory Measurement of Rock Properties[3]	Saturation/vacuum chamber, CO_2 gas, balances, drying ovens Miscellaneous lab equipment and supplies (beakers, ringstands, etc.) Temperature and humidity measuring equipment Permeameter chamber, flow and pressure measuring equipment, recording equipment and/or personal computer

1. Drilling and direct support activities are conducted by Nevada Test Site support contractors (Reeco, Raytheon Services Nevada).
2. Initial sample collection, photography, and processing are conducted by the Yucca Mountain Sample Management Facility operated by Science Applications International Corporation.
3. Laboratory techniques to be coordinated with Study 8.3.1.2.2.3.

3.10 Data Reduction Techniques

Data obtained by geologic logging of core will be placed on graphic log forms at an initial scale of 1 inch-to-10 feet (1:20), a scale that typically is adequate for representing information of this kind. Intervals of complex geology or features of special interest may be portrayed at an expanded scale appropriate to the interval. Percentage core recovery and RQD values are easily calculated by mental arithmetic or with the assistance of a hand calculator or simple computer program.

The data to be obtained as part of the laboratory properties measurements that are under the direct control of this study are essentially all weight (masses). Permeability measurements involve measurement of mass, but also of pressure and time. These weights are converted into the bulk properties and hydrologic state variables (Table 3.4) through simple algebraic relationships, and the computations are easily performed with a hand calculator or Lotus®-style computer spreadsheet. Permeability is likewise computed from simple, if slightly more complicated, algebraic relationships.

The synthesis and interpretation of these results and other data collected as part of this study depends upon the experience of the principal investigator(s) and support staff. Evaluation of the spatial structure as revealed by laboratory rock properties information will be performed through the use of both classical and geostatistical methods. These techniques are described in widely used textbooks and other references (Journel, 1978; Clark, 1979; Isaaks and Srivastava, 1989).

3.11 Representativeness of Results

The Systematic Drilling Program will acquire samples and data from the repository block and vicinity, both areally and from the topographic surface to below the water table. This information will be combined with data obtained by other studies from the same three-dimensional volume of rock. These studies include the drilling-related programs listed in Table 2.1, but will also include surface and Exploratory Studies Facilities activities such as will be conducted under Study 8.3.1.4.2.1 (Characterization of Stratigraphic Units) and 8.3.1.4.2.2 (Characterization of

Structural Features). Drill hole locations for the integrated drilling program have been selected to provide both areal coverage at approximately 2,500- to 3,000-ft (750-900 m) intervals and details of the spatial structure at smaller separations. Down-hole samples will provide vertical coverage at roughly one-meter spacings.

To the extent that these combined studies provide samples from an area that covers the entire repository environment, the data collected are -- by one definition -- representative. Much discussion has focused on the accuracy of expected values, another definition of representative. Barnes (1988) provides an interesting discussion of another alternative approach to the issue: that the spatial "average" value is not the objective, but rather the purpose of site characterization is to realistically reflect the extreme values of a variable. The application of geostatistical techniques to the data obtained from the integrated drilling program will provide several quantitative estimates of representativeness. Risk-qualified estimates (Journel, 1983) of the various rock properties can be provided, if required.

3.12 Performance Goals and Confidence Limits

The performance allocation process has identified the performance goals and confidence levels required to resolve the key issues addressed by the study plan. These performance goals and associated confidence limits of parameters to be provided by this study are summarized in relatively high-level "model elements" of Yucca Mountain in SCP Tables 8.3.1.4-1 and 8.3.1.4-2. More detailed descriptions of performance goals and confidence intervals for individual parameters as required by SCP activities using these parameters are found in many locations throughout the SCP (Table 3.8). The majority of parameters obtained by the Systematic Drilling Program generally are those related to rock-unit contacts and configurations, fractures and faults, and those collectively referred to as "geologic framework" or "geologic model."

Table 3.8 Performance Goals and Confidence Limits for Parameters to be Measured on Samples Obtained by the Systematic Drilling Program

Design or Performance Assessment Issue and Brief Description	Detailed SCP Table of Performance Goals and Confidence Limits
1.1 - Total Releases	8.3.5.13-8
1.6 - Ground Water Travel Time	8.3.5.12-1 8.3.5.12-2 8.3.5.12-3
1.10 - Waste Package Performance	8.3.4.2-1
1.11 - Post-Closure Design	8.3.2.2-1 8.3.2.2-5 8.3.2.5-2
1.12 - Sealing	8.3.3.2-3 2.3.3.2.4
2.4 - Retrievability	See Issue 4.4

Table 3.8 Performance Goals and Confidence Limits for Parameters to be Measured on Samples Obtained by the Systematic Drilling Program

Design or Performance Assessment Issue and Brief Description	Detailed SCP Table of Performance Goals and Confidence Limits
2.7 - Preclosure Design/Performance	8.3.2.3-3
4.2 - Non-radiological Safety	8.3.2.5-2
4.4 - Repository Operation/Closure	8.3.2.5-2

The samples to be obtained through this study will provide many of the actual measured values for a large number of the parameters requested by the performance assessment and design issues. The geostatistical evaluation of this suite of objective data (Tables 3.2. 3.4, and 3.5) -- the confidence level of which is generally quite high -- will allow quantitative evaluation of the uncertainty associated with the overall understanding, or model, of the particular parameter in question. In general, the greater the degree of spatial correlation exhibited by a particular rock property, the higher the overall confidence in models of that property's distribution in space. Also, the more highly correlated a group of properties, the higher the confidence in models of those properties. If the degree of spatial or inter-parameter correlation is small, the drilling density described in this study may need to be increased in order to achieve the same level of confidence, all other factors remaining equal. A potential approach to uncertainty assessment as it affects the results of performance assessment calculations, such as ground water travel time estimation, has been discussed by Rautman and Treadway (1991). Some implications of spatial heterogeneity for performance modeling are discussed by Rautman and Flint (1992). Other approaches and/or methodologies, no doubt, are also possible (see, for example, Kaplan, 1991). Full assessment of the effects of characterization uncertainty *vis-a-vis* performance is beyond the scope of this Study Plan.

4.0 APPLICATION OF RESULTS

The results of this study will be used both directly and indirectly in a large number of design and performance assessment issues. In addition, there are a large number of site characterization studies that depend upon the results of this study, typically for sample materials to support testing activities.

4.1 Application of Results of Resolution of Performance Assessment Issues

A primary use of the results of this study is to resolve performance issues related to the two "geologic" or "site-oriented" regulatory licensing criteria: (1) the pre-waste emplacement ground water travel time requirement, and (2) the total systems radionuclide release requirements. These are Issues 1.1 and 1.6 in Table 1.2. These and most of the other issues listed in the table depend upon a physical description of the site or upon a modeling interpretation of the site based upon such a description. A well documented, accurate, geometric representation of the Yucca Mountain site is essential to resolving virtually all performance issues. This is reflected at a highly simplified level in the majority of the Information Needs listed in Table 1.2 as "*site* information required for ...." Some "components" of the geometric description of Yucca Mountain (the "site information" of the Information Needs) are listed in Table 3.2.

In addition to a geometric description of the Yucca Mountain site, quantitative assessment of ground water travel time, radionuclide release rates, and other performance assessment measures require input descriptions of physical rock properties (rock characteristics) to allow numerical calculations. These input descriptions of material properties are required on a wide variety of scales and levels of detail. At one level, performance assessment calculations may only require a mean and variance for, say, hydraulic conductivity. At another level, calculations may be based upon a detailed, three-dimensional representation of a number of cross-variable- and spatially correlated rock properties in the immediate vicinity of some deterministic (geometric) feature such as the Ghost Dance fault. Some of the "rock characteristics" that result from this study are listed in Tables 3.2 and 3.4. However, the full variety of "site information" (which term really reflects and encompasses various combinations and the interplay of such rock characteristics) required to resolve all performance assessment issues is nearly as wide as the entire Site Characterization Plan, and is certainly beyond the scope of this Study Plan.

Although detailing how the information derived from this study will be applied to the resolution of all performance assessment issues is beyond the scope of this document, it is clear that a unifying means of understanding that application is through the concept of models.[1] The full three-dimensional, computer-based, geologic and rock characteristics models of the site, which eventually will incorporate the results of this and other site characterization studies, will represent both the geometric framework of the mountain (based on identifiable stratigraphic units) and the continuously variable rock-properties (based on interpolation and/or simulation of measured values). Because site characterization data are, themselves, simply a collection of measurements or

1. *Models*, as used in this section, includes both deterministic "best-estimate" models and multiple stochastic simulations or "images" as described by Journel and Alabert (1989). The word implies a description of geology and other rock characteristics, and not a hydrologic or flow model.

other observations, the immediate results of this study simply constrain the models, which are the "useful" results.

Use of three-dimensional geometric models is relatively intuitive: knowing where things are is a fundamental basis for understanding how a system behaves. The utility of the rock characteristics models is more complex and tends to be application specific. However, it should also be intuitive that a detailed three-dimensional representation can be simplified to meet the needs of a wide variety of users. Two-dimensional cross-sections, one-dimensional profiles, and even non-dimensional (spatial dimensions) distributions of values can be extracted as required. Furthermore, the simplifications are easily understood in their original context, which can add to their credibility for certain purposes. A simplified, one-dimensional example of the application of the stochastic-simulation approach to performance assessment modeling as applied to Yucca Mountain, in which descriptive rock characteristics models are coupled to a hydrologic flow model, has been presented by Rautman and Treadway (1991).

4.2 Application of Results of Resolution of Design Issues

Application of the results of this study in resolving design issues is most directly understood through the concept of the geometric model outlined immediately above. If the potential repository is to be constructed in a certain portion of the Topopah Spring Member of the Paintbrush Tuff, then knowing where that unit is in space is critical to the design of the repository. The need for this type of information has been expressed repeatedly as "site information needed for ..." in the design-related information needs of Table 1.2. Three-dimensional models of the site are required for engineering design of the underground facilities, the engineered barrier system, shafts and ramps, and the Exploratory Studies Facility.

Much of the discussion of three-dimensional rock characteristics models previously presented in terms of performance assessment (Section 4.1) applies equally well to the more detailed aspects of design calculations. Numerical representations of physical rock properties are required to support design computations of drift stability, thermal loading, heat dissipation, and similar aspects of repository design. Detailed discussion of exactly which models will be created and how they will be used based on the information resulting from this study and other studies that will test samples obtained by this study is obviously beyond the scope of this Study Plan.

4.3 Application of Results to Other Site Characterization Studies

In addition to the application of results from the Systematic Drilling program by activities in the areas of performance assessment and design, a wide variety of other site characterization studies (Table 1.1) depend upon this study as well. Significant discussion of the direct use of physical sample materials and the drill holes themselves from the Systematic Drilling Program is presented in Sections 1.3, 2.1.1, 2.5, 3.3, and 3.4 of this Study Plan.

It should be noted the evaluation of information being obtained by these various studies in terms of adequacy in characterizing the site (Section 3.5) is a unifying theme pursued by this study. Information obtained from holes drilled early in the program will be used to evaluate and to modify ongoing site characterization studies, if required. Preliminary estimates of spatial correlation (Table 2.2) will be confirmed or revised. Holes planned by studies such as the Systematic Drilling Program itself or other components of the integrated drilling program (Table 2.1) may be relocated or additional drill holes scheduled. Sampling programs being conducted by various SCP studies (Table 1.1; including this study) may need to be modified based on such early results in order to prevent significant over- or undersampling of the site.

Other site characterization studies will use portions of the information as well. A detailed (although not necessarily complete) discussion of the relationships between some site characterization results and the relevant design and performance assessment issues is presented in SCP section 8.3.1.4 and specifically in SCP Table 8.3.1.4-1.

5.0 SCHEDULE AND MILESTONES

The work planned as part of this study is composed of one formal (SCP) activity. However, this activity, the Systematic Drilling Program, may be thought of as a sequence of five repeating tasks or subactivities (Figure 3.1).The schedule for the Systematic Drilling Program is strongly influenced by the logistics of drilling, a notoriously difficult type of endeavor for which to maintain a schedule. However, because many similar drilling efforts are planned as part of site characterization, difficulties encountered in drilling holes for the Systematic Drilling Program are likely to cause similar problems in other programs. Thus, whereas the entire repository schedule might be delayed by unanticipated logistical problems, it is unlikely that the Systematic Drilling Program would be the unique cause of that delay.

Because of the intimate and inescapable tie between the Systematic Drilling Program and the repository block, it is essential that most, if not all, of the Systematic Drilling Program be completed in time to provide input to advanced conceptual design. If an insufficient and/or inaccurate geologic model of the site is used in advanced conceptual design, some unpredictable fraction of those design efforts might need to be redone. A major redesign effort might require delays in the license application design, if the errors were significant enough. Propagation of significant design delays probably would result in delaying the formal license application, and potentially the start of construction and/or operation of a repository. Separate from the issue of schedule delays due to inadequate geologic models of the site is a concern with early construction of facilities (such as the Exploratory Studies Facility) that technically are part of site characterization, but which are intended to be incorporated into the ultimate repository facility. Without information from certain critical drill holes of the Systematic Drilling Program, various features of the Exploratory Studies Facility, such as test levels and breakout rooms, cannot necessarily be located accurately enough to allow construction. In a worst case scenario, mislocating major engineered features of the ESF/repository might limit the usefulness of those facilities for their intended purposes.

5.1 Scheduling Relative to Other Studies

5.1.1 Drilling

The relationship of the Systematic Drilling Program to other studies that involve drilling is constrained by the availability of drilling equipment. The proposed, tentative sequence of drill holes for this study is discussed below in Section 5.2. Logistical integration of Project drilling activities generally will be accomplished by interspersing drill holes from different programs in an evolving actual field schedule. Examples of other major drilling programs include Regional Ground-Water Flow System (Study 8.3.1.2.1.3), Unsaturated Zone Percolation (Study 8.3.1.2.2.3), Multipurpose-Borehole Testing (Activity 8.3.1.2.2.4.9), Saturated-Zone Ground-Water Flow System (Study 8.3.1.2.3.1), and Characterization of ... Stratigraphic Units (Study 8.3.1.4.2.1) (see Table 2.1). The principal impact of these other drilling efforts on the Systematic Drilling Program would be to delay (or accelerate) holes of the SD- program depending upon the execution of the other drilling efforts. Overall integration of the Project drilling schedule is the subject of SCP Activity 8.3.1.4.1.1, which is the responsibility of the Yucca Mountain Site Characterization Project Office.

Initiation of drilling for any particular hole (SD- program or not) is contingent upon completion of the previously scheduled hole and operational availability of the drilling equipment. Nevada Test Site drilling procedures require periodic, comprehensive rig certification evaluations; these are estimated to require 30 days of downtime approximately once a year. Some of the other drilling studies (notably Unsaturated Zone Percolation) currently call for an extended period of down-hole testing. Retaining the specialized dual-wall, reverse-circulation drilling equipment for an extended period of down-hole testing for periods of up to several years for monitoring and testing purposes is obviously unsatisfactory to all parties. The main drilling equipment will be released upon completion of actual drilling, and a subsidiary drill rig and equipment provided to support hole instrumentation and testing.

Because many contingencies are involved in the Project drilling effort, the drilling schedule will be continually revised. It is impossible to speculate regarding specific events and situations that may need to be addressed over the course of site characterization drilling. However, there will always be numerous options for the "next" hole should a particular rig be delayed or become available unexpectedly. Each major Project drilling program (Table 2.1) consists of a suite of holes that are intended to accomplish the goals of the relevant study or investigation. Site drilling is a major aspect of site characterization, and Project-level decisions will be required with respect to drill hole prioritization and scheduling in light of the then-current limitations of manpower, budget, equipment availability, and programmatic needs for samples and information. However, it is clear that major delays anywhere in the drilling effort would have significant effects on the Yucca Mountain schedule for advanced conceptual and license application design. Potential impacts include delays in submittal of the license application.

5.1.2 Exploratory Studies Facility

The exact relationship of this study to other studies to be conducted in the Exploratory Studies Facility is unclear because of the evolving schedule and plans for the Exploratory Studies Facility. Accordingly, no specific description of these relationships is possible. Initiation of surface-based work for this study is not dependent upon the plans or schedule for the ESF.

Generally, the sampling to be conducted by this study in the Exploratory Studies Facility is anticipated to be along the long main drifts of the ESF. Sampling anticipated by this study would be "incidental" sampling, and consist of removing a small core plug a few inches (cm) long or a small hand specimen at regular intervals along accessible workings (see Section 2.2.4). The requirements for location and spacing of samples is sufficiently flexible that any conflicts that are identified as plans for other ESF testing activities are finalized can be resolved simply by not collecting within a to-be-agreed-upon standoff distance from the other test locations. It is unlikely that the testing to be performed by this study on samples from the Exploratory Studies Facility would be compromised by any anticipated testing in the ESF.

5.1.3 Sampling and Laboratory Testing

A number of SCP studies (Table 1.1) are wholly or partially dependent upon the Systematic Drilling Program for sample materials on which to conduct various types of laboratory tests (Table 3.5). The intent of most, if not all, of testing studies listed in Table 1.1 is to provide early input to advanced conceptual design, followed by more detailed information to be used in the license application design. Obviously, testing activities that are predicated upon the availability of certain samples cannot be undertaken until those physical materials are available. In similar fashion, any performance assessment or design activities that depend upon the results of this testing cannot begin or progress beyond a certain stage without those test data. Any performance assessment or design analyses that are conducted on the basis of preliminary information thus is subject to revision once more complete information is available.

Although it is not possible to indicate specific temporal relationships between the Systematic Drilling Program and the laboratory-testing activities that depend upon the drilling program for samples (Table 3.5), the unique, close tie between this study and the repository block and the logic diagrams of Figures 2.2 and 3.1 do have some qualitative implications for scheduling. Specifically, it is important to start *some* holes of the site-specific Systematic Drilling Program as soon as possible. Early initiation of the Systematic Drilling Program will produce samples early in site characterization that can be distributed to the testing studies that require them through the process described in Figure 2.2. Thus, physical properties testing can begin early, with the early results forming the basis for a crude-but-first-pass evaluation effort to identify any gross discrepancies between the Project's pre-site characterization understanding of the site and the new data. Additionally, the descriptive information from the first drill holes (Table 3.2) will provide significant information to confirm or revise the pre-site characterization understanding of the overall, immediate repository block. To accentuate the areal-coverage aspect of this Study Plan (see Section 2.2.2), the first several holes will be located in diverse geographic portions of the study area (Figure 1.3). Although the specific sequence described in Section 5.2 is subject to change as site characterization progresses, these philosophical concepts have been incorporated into the schedule as described below.

5.2 Schedule and Milestones

The schedule for this study is based upon approval of the study plan and completion of relevant procedures at least thirty days before work begins. Delays related to the approval of the study plan and associated documents, such as readiness reviews, job packages, funding authorizations, and so on will have corresponding effects on the execution of the study.

The preliminary proposed sequence of drill holes (SD prefix) for this study is shown in Figure 5.1. This sequence is subject to modification as the drilling program progresses and information is gained from the initial drill holes. Also, the sequence is "incomplete," in that it addresses only holes of the Systematic Drilling Program. In practice, SD-prefix holes will be interspersed with drill holes officially "belonging" to other SCP Studies (see also discussion in Sections 2.5 and 3.1). The sequence may also be impacted by the number of drill rigs available. Figure 5.1 is constructed as if each SD drill hole were conducted in simple sequence, one after the other with no gaps. The availability of more than one piece of drilling equipment may allow more than one SD hole to be in progress at any time.

A description of the interrelationships of each of the five-task sequence of the Systematic Drilling Program is presented in the discussion associated with Figure 3.1. These repeating sequences of work activities are portrayed on a tentative, and idealized, timeline in Figure 5.2.

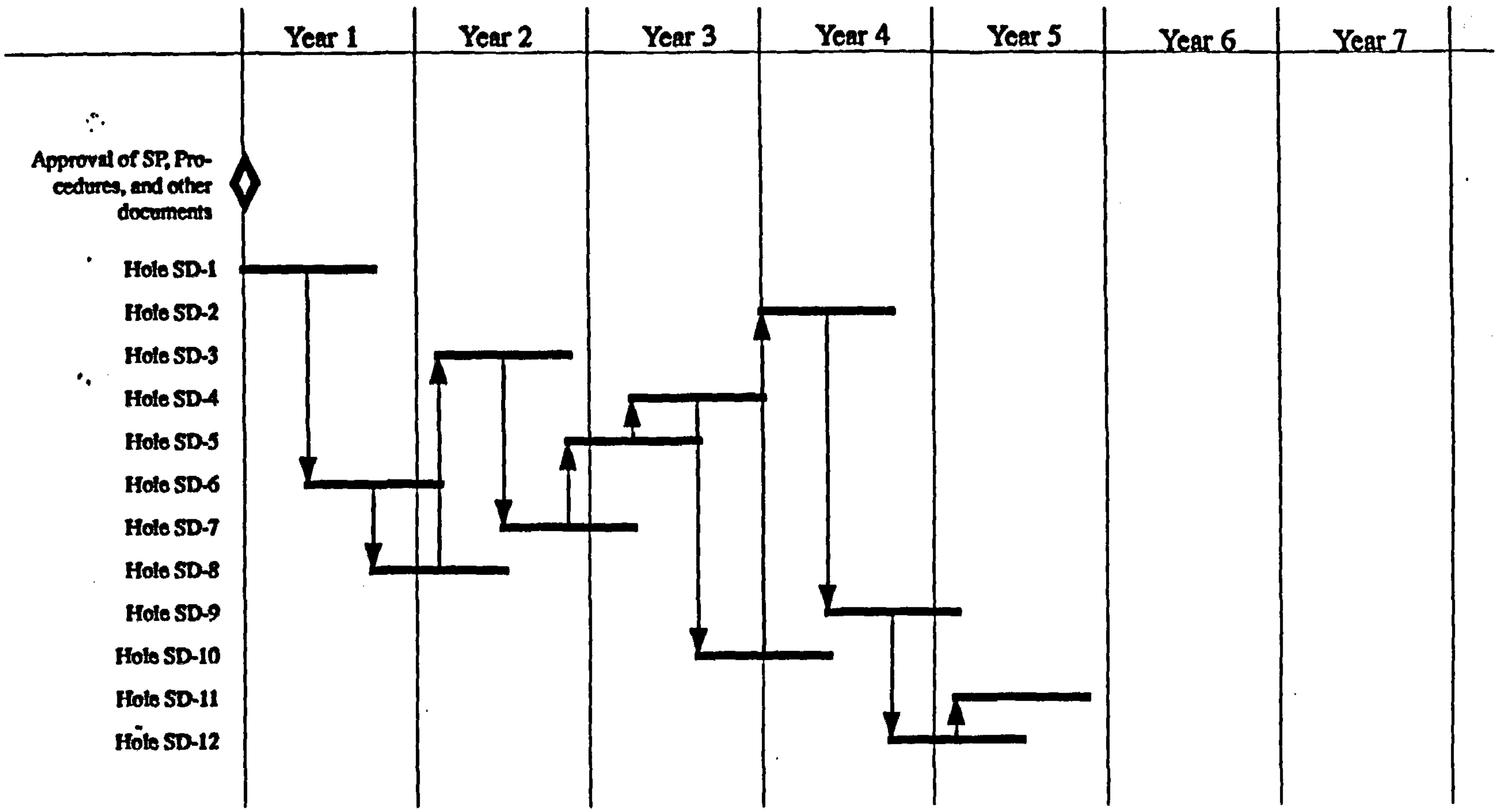

Figure 5.1 Schedule and tentative sequence of holes for the Systematic Drilling Program. Each bold bar corresponds to a complete cycle of tasks and associated work activities as shown in Figure 5.2. Initiation of next hole depends upon availability of drilling equipment and integrated Project drilling schedule (conceptually shown by linking arrows in figure). A report is issued for each drill hole, which serves as the feed to other activities using data from the Systematic Drilling Program.

Drilling of the hole (Task 1) is followed by geologic logging (Task 2), which will be performed on an ongoing (essentially daily) basis as the hole is drilled. Logging should be completed within a week or so of reaching total depth of the hole. The completed log will be reproduced and released on an informal basis to every principal investigator who has an interest in samples or other information from the specific drill hole, as identified through preparation of the job package for that hole. Geophysical logging (Task 3) may occur at any time during or immediately after drilling as indicated by hole conditions and rig-site activities. Laboratory testing (Task 4) by this and other studies will follow distribution of core samples by the Project Sample Management Facility, which may occur virtually as soon as the core from a given interval has been logged geologically. Evaluation of the data (Task 5) will begin once the majority of laboratory data are available. The sequence of work activities is concluded with the release of a drill hole report.

Major milestones for the Systematic Drilling Program are summarized in Table 5.1

Table 5.1 Major Milestones for the Systematic Drilling Program

Event	Description
Z963	Study Plan for the Systematic Drilling Program
Q093	Begin Phase I of Systematic Drilling Program
Q101	Complete Phase I of Systematic Drilling Program
Z435	Complete Compilation of Phase I Data for ACD
Q102	Begin Phase II of Systematic Drilling Program
Q118	Complete Phase II of Systematic Drilling Program
Z436	Complete Compilation of Phase II Data for LAD
Note:	Milestones for the Systematic Drilling Program may be tied flexibly to major Project events such as ACD and LAD. The drilling completed at any specified date can simply be compiled and reported as of that moment, and thereafter used as the design basis for the appropriate design phase. The implications of this approach for data adequacy are discussed in the text (see Section 5.1.3.

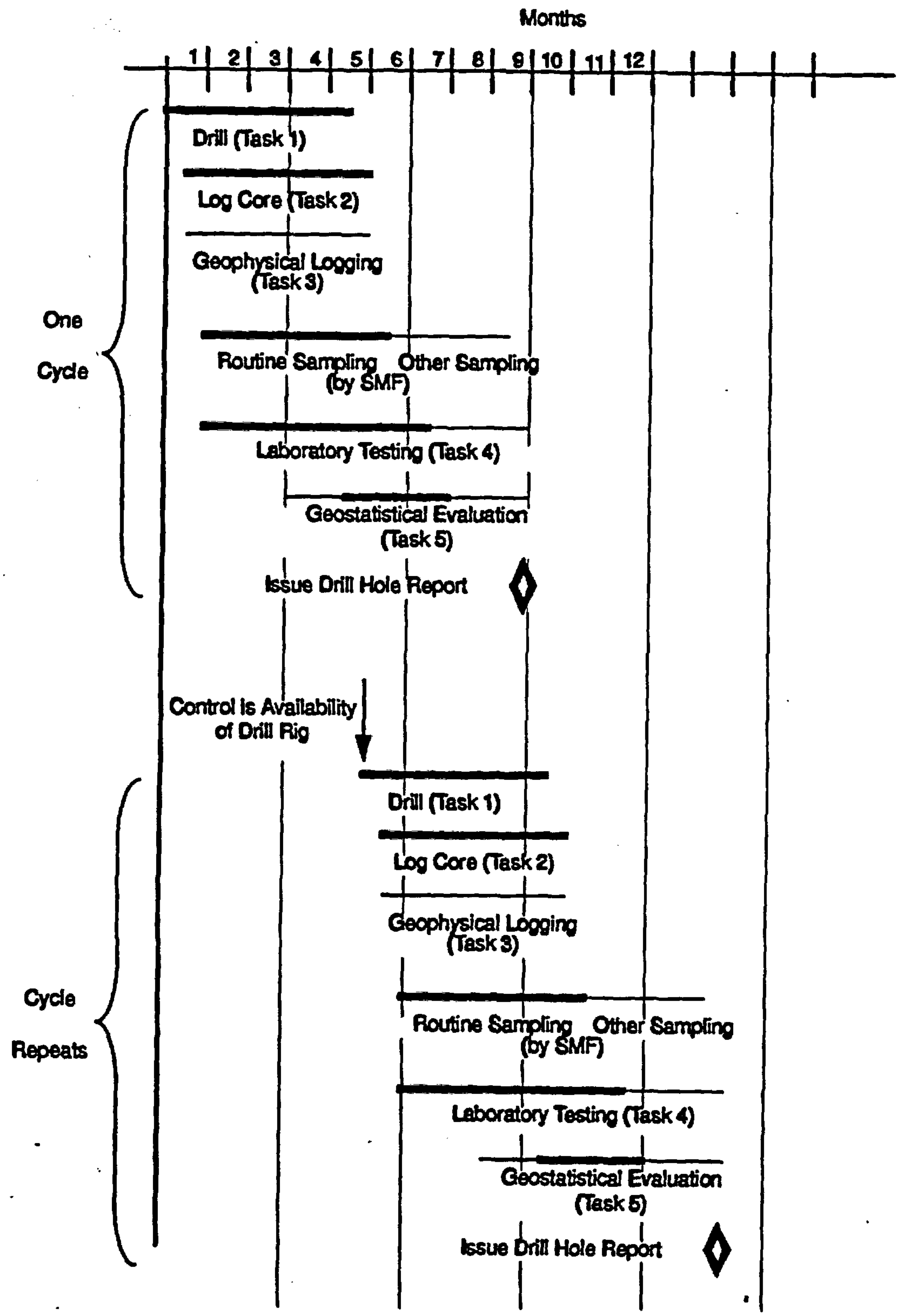

Figure 5.2 Idealized schedule of tasks and associated work activities for the Systematic Drilling Program. Sequence is accurate, but specific timing is highly conceptual. Bold bar indicates duration of continuously ongoing activities; activities represented by light bar that may occur at any time during the interval.

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