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Long-Term Mechanical Behavior of Yucca Mountain Tuffs, and its Variability

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Scientific Investigation Plan (SIP)

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REVISION HISTORY

Revision Number	Effective Date	Description and Reason for Change
0	10/20/2004	Initial Issue

Table of Contents

1.0 Scope and Objectives

The objective of the work to be performed under this Scientific Investigation Plan is to study the "Long-Term Mechanical Behavior of Yucca Mountain Tuffs, and its Variability."

This Scientific Investigation Plan (SIP) outlines a partial continuation of the work performed under Task 18, Long Term Drift Stability, of Cooperative Agreement DE-FC28-98NV12081. Task 18 was completed under University and Community College System of Nevada (UCCSN) Quality Assurance (QA) Program Requirements.

This work is subject to University and Community College System of Nevada (UCCSN) Quality Assurance (QA) Program Requirements.

This Scientific Investigation Plan presents an independent confirmatory study.

This Scientific Investigation Plan summarizes the planned continued investigation of the mechanical behavior of Yucca Mountain tuffs. The continuation of the drift support/reinforcement corrosion studies initiated under Task 18 is addressed in a separate Scientific Investigation Plan.

1.1 Scope

The investigation to be conducted includes creep testing (static fatigue), constant strain rate or constant stress rate testing (dynamic fatigue), over a wide range of rates, and cycling testing (cyclic fatigue). Testing will be conducted in uniaxial and triaxial compression, and in indirect tension (tensile splitting - Brazilian testing). The latter data in particular, because it can be obtained quickly, should allow us to complement the investigation of time-dependency with one of spatial variability.

We propose to continue the investigation of the long term strength of Yucca Mountain tuffs, with particular emphasis on tuffs from and near the emplacement horizon. We propose to also continue and expand the investigation of the spatial variability of rock strength and stiffness. An intrinsic component of this planned rock testing is the testing of rock joints. Although the emphasis is on tests aimed at determining long term strength, as part of the testing measurements of stiffness also are collected, and will be collected, reported, and analyzed.

Results of rock testing performed during the previous contract have been given in the final technical report (http://hrcweb.lv-hrc.nevada.edu/qa/Report.htm).

1.2 Objectives

In the previous task we found that microfracturing governs the deformation and failure of the tuffs. In the current task, we will conduct more tests to verify this finding, and explore the time dependent constitutive behavior and the failure criterion of the tuffs based on our finding.

The objectives of the investigation are to study the long term mechanical behavior of Yucca Mountain, with emphasis on an approach to determine the long term strength of the tuffs. It is assumed that the in situ long term loading of the tuff essentially will be static, although it is recognized that there may be pseudo-static load (stress and strain) fluctuations (e.g. thermal loading and unloading), as well as occasional truly dynamic effects (earthquake loading). A major objective is to try to determine a "safe" load/stress level, i.e. a stress level below which it is most unlikely that fracturing would develop in the tuff. A combination of test methods, including uniaxial and triaxial creep, testing at a range of constant strain and/or stress rates and cycling testing will be conducted to achieve the planned objectives.

2.0 Approach

The planned rock testing is subdivided into three main tasks, long term compressive strength and deformational behavior testing, investigating the spatial variability of tuff properties by means of tensile strength testing, and testing of rock joints.

Task 1 Long term compressive strength and deformational behavior testing of tuff.

Subtask 1.1 Sustained load testing ("creep" testing; static fatigue testing).

Under this heading we propose to continue sustained load testing of repository horizon and nearby tuffs. The intent is to establish a sufficiently large independent experimental data base to allow a statistically significant assessment of the anticipated long term strength of the repository horizon host rock, with emphasis on the horizons/formations where most waste will be emplaced.

The primary approach to this testing is to estimate the ultimate strength of a sample, load the sample to about 80% of its ultimate estimated strength, sustain the load for a given period, typically for at least 3 to 7 days, observe any deformations that occur over this time. If no systematic deformation increase is observed, and if the sample has not failed, the load on the sample is then increased, typically by between 5 and 10 % of the already applied load, and this load then is maintained either until a clearly established progressive deformation increase is observed, or for at least three to seven days. If at the end of this period no systematic measurable deformation is observed, an additional load increment is applied. These steps are repeated until the specimen fails.

Because of the intrinsic variability of the strengths of the tuffs tested, it is difficult to estimate in advance the appropriate load level. As a result, it occasionally happens that a specimen fails during the initial load application. While not desirable, this does provide us with one more measurement of the uniaxial or triaxial compressive strength, and certainly is not a complete loss. It provides a strength value after some period of sustained loading, but integration within the overall data basis of strength as a function of load duration may be complicated by the fact that in this case the specimen already may have been subjected to earlier loading steps. Several times a specimen has broken shortly after the application of a load increment (i.e. within 2 hours), confirming the suspicion that these tuffs are susceptible to deformation under constant stress over a fairly narrow stress range only, i.e. in order to observe significant, i.e. statistically measurable time-dependent deformation, the applied uniaxial stress must exceed a significant fraction of the ultimate strength of the rock. Because of the uncertainty in predicting the load level at which a sample will fail, it usually happens that multiple load steps must be applied before the eventual failure level is reached. The result is that these experiments become very time-consuming, at least with regard to test machine commitments, as each load step is maintained for 3 to 7 days, and it probably would be desirable to extend the loading steps over a longer period of time.

In order to provide an alternative, complementary approach to long term strength determinations, we will investigate the feasibility of cycling the load/stress during some tests, in order to evaluate the feasibility and reliability of establishing long term strength through such cycling. In particular, it would be valuable to try to confirm the conclusion from the previous study that for constant stress testing at a stress level below about 50 % of the uniaxial compressive strength no creep is observed, presumed to imply that no damage is inflicted, while at above 94 % creep always accelerates into failure. By performing cyclic testing at and near these stress levels we hope to develop an alternate independent confirmation of these damage threshold points/stress levels. (e.g. Eberhardt et al, 1999). We recognize that, as so often, the intrinsic variability of tuff properties is likely to cause interpretation problems, e.g. for establishing some fatigue life strength (e.g. Peng et al, 1974), or some long term strength, vs. the conventionally determined strength, given the high variability and uncertainty about the latter.

Subtask 1.2 Compressive testing at constant strain rates over a range of constant strain rates (dynamic fatigue testing).

A second major aspect of this test phase is to conduct constant strain rate tests over a wide range of strain rates (from about $10^{-8}/s$ to about $10^{-3}/s$). These results will be used to estimate long term strength of the rock. This approach has been implemented with reasonable success as part of the previous task (it will be added to Revised Technical Report, Part 2, Chapter 2). The intrinsic high variability of tuff properties leaves a great deal of uncertainty about the results, which we hope to reduce at least somewhat by conducting additional tests, and by improve control on some variables, in particular L/D (length to diameter) ratio and moisture content. Dynamic fatigue testing will be performed in uniaxial and triaxial compression, and by indirect tensile splitting (Brazilian testing).

Common aspects of subtasks 1.1 and 1.2:

We propose to conduct a significant fraction of the tests aimed at studying time dependent failure in compression in triaxial testing, thus extending the range of results from the previously performed uniaxial compression testing. Triaxial testing will be conducted at a range of confining pressures.

For most of these tests the stiffness (Young's modulus, Poisson's ratio), or deformational behavior, is monitored in several ways: electric resistance strain gages are installed on most specimens (typically at least two axial and two lateral gages), and extensometers (usually axial only) are installed on the specimens (we usually try to remove extensometers before failure, because failure tends to be extremely brittle and violent, and extensometers are highly susceptible to damage and to calibration problems when subjected to shock loads). In addition, we have overall deformation measurements monitored by the MTS machine LVDT, although this measurement includes the machine, load cell, etc. deformations as well as the rock deformations, and these extraneous deformations are not easily separated, especially in light of the very small deformations observed.

Strain gages mounted on lithophysal samples are installed at judiciously selected locations near or around lithophysal cavities. The main objective of these strain gages is to provide supporting information about deformation and strain near cavities, and thus assist in identifying developing failure patterns (i.e. as distinguished from nonlithophysal samples, where the purpose is to measure "average', 'representative", strains, in order to determine rock stiffness properties).

In order to improve the data collection during these experiments we propose the acquisition of an acoustic emission monitoring system. It is fairly common to observe audible signals of impending failure during testing of the usually exceedingly brittle tuffs, yet even when fracturing is heard, the stress-strain relations often, usually, remain remarkably linear. It also is common to see indications of impending failure, i.e. small rock particles falling or shooting off specimens.

We would like to quantify the early indications of failure by acoustic emission monitoring, and conversely, evaluate to what extent it may be possible to anticipate or predict failure based on such monitoring. We also plan to use the acoustic emission monitoring system to try to obtain a better understanding of where failure initiates when testing rock specimens containing lithophysal cavities or soft altered inclusions, and how such failures propagate. An enhanced phenomenological, descriptive understanding of lithophysal collapse, failure development in lithophysal samples, will provide deeper insight as to how actual repository excavations in such formations might behave. While sometimes it has proven possible to observe and monitor failure initiation visually, such visual observation obviously is limited strictly to the surface of the specimens, and certainly does not allow for ready quantification or failure analysis.

Dynamic properties (Young's modulus E, Poisson's ratio ν, and longitudinal and transverse velocities) will be determined using the ultrasonic velocity measurement unit.

Based on observations at the SMF (Sample Management Facility), we expect that obtaining samples for these tests should not pose a problem.

We anticipate that the nominal diameter of the samples will be 2.4 inches.

Task 2 Testing spatial variability of rock strength and stiffness: tensile strength testing of tuff

We propose to continue and expand the relatively simple experiments, i.e. Brazilian (tensile splitting) testing. Samples for these tests are readily available (because they require only relatively short core) from many different locations. This will allow us to cover in more depth the spatial variability investigations of the rock properties of the repository and nearby horizons. This phase of the experimental work will provide an extensive data base on tensile strengths of the host rock, as well as of stiffnesses measured during these tests. As one component of the Brazilian tensile testing we propose to include testing strength variability as a function of moisture content. We will increase the moisture content of a significant number of specimens by immersion in water, and alternating vacuum and applied pressure. Specimens will be surface dried (wiped with a moist cloth; Franklin et al, 1981) prior to testing, and will be surface protected against evaporation during testing.

Task 3 Rock joint testing

We propose to continue and expand the testing of the mechanical properties of rock joints of concern with regard to the stability of emplacement drifts.

We will continue the testing of vapor phase altered rock joints, typically dipping at shallow angles across the proposed repository horizon, because we have readily obtained multiple samples of these joints. Usually these joints cut across core, and allow us to test the normal stiffness of these joints in uniaxial compression testing. All indications are that these joints are too strong to be tested in direct shear. On occasion, although rarely, we have obtained core with joints of these sets at a fairly steep angle, making them excellent potential candidates for triaxial testing, which we intend to perform on these samples, and/or for the experimental determination of the shear stiffness of these joints.

If we could obtain more samples of the steeply dipping tensile joints we would like to test such joints, both in direct shear and in triaxial (confined) conditions, in order to determine strength, and shear as well as normal stiffness of joints of these families. Of particular interest would be cyclic and sustained load testing, in order to estimate the time-dependent behavior of these joints, and in particular asperity deterioration, if any, during sustained discontinuity loading.

General comments:

The outlined test program depends critically on the availability of samples. We have no samples on hand to initiate the outlined testing, hence it is essential that we be able to collect samples as soon as possible, or have testable samples shipped to us as soon as possible. It would be preferable to have some different types of samples, especially of the joint systems that are most likely to affect the stability of repository excavations.

The maximum number of tests compatible with the capacity of the laboratory equipment is critical for the long term testing, i.e. creep tests and constant strain tests at very low strain rates. We have two machines on which such tests can be performed. Assuming that both machines will be available for 18 months (after subtracting contract time for start up and close out paperwork, estimated time for breakdowns, etc..), we have an estimated total machine time of 36 months. Assuming a total creep test duration of three months, running six creep tests will take up 18 months. Assuming 6 very slow constant strain rate tests, at one month each, takes up another 6 months. That leaves 12 months for short term tests, i.e. sufficient time to perform 8 one-week tests, and up to 200 one-day tests.

3.0 Project Schedule with Milestones and Deliverables

Year 1 Quarter 1: QA training, SIP preparation, post doc, technician and grad student recruiting

Quarter 2: QA training, IP preparation, instrument calibration, sample collection, instrument acquisition

Quarter 3: Testing and data analysis

Quarter 4: testing and data analysis

Year 2 Quarter 1: instrument calibration, testing, data analysis, sample collection

Quarters 2 through 4: testing and data analysis

Year 3 Quarter 1: instrument calibration, testing, data analysis, sample collection

Quarters 2 and 3: testing, data analysis, final report preparation

Quarter 4: instrument calibration, final report preparation

Quarterly reports will be submitted at the end of each quarter. A final technical report will be submitted at the end of the project. Technical progress reports will be submitted in the form of technical publications, most likely starting in the second year.

4.0 Interface Controls

The QA group of the Harry Reid Center for Environmental Studies at UNLV provides "Qualification, Indoctrination and Training of Personnel" in accordance with UCCSN

QAP-2.1.

All quality-affecting procurements of equipment, instrumentation, calibration services, hardware and software are made through UCCSN North purchasing, with approval of the Harry Reid Center Quality Assurance Manager and following UCCSN QAP-7.0 “Control of Procurement and Receipt.”

All deliverables will be delivered to the UCCSN Quality Assurance group of the Harry Reid Center for Environmental Studies at UNLV, in the format requested by the Center.

UNR personnel:	Jaak Daemen	PI
	Lumin Ma	Graduate Student Research Assistant (July 1, 2004 – August 13, 2004), Post Doctoral Research Associate (from September 16 on)
	Rick Blitz	Laboratory coordinator
	Cheryl Breland	Management Assistant
	Jerry Best	Manager, Grants and Contracts
	William Bailey	Manager, Purchasing

QA interfaces:	Amy J. Smiecinski	UCCSN QA Manager
	Robert W. Fulwider	Quality Assurance Specialist
	Morrie Roosa	Quality Assurance Specialist
	Barbara Roosa	Document Control Coordinator, Training Coordinator, QA Records
	Raymond Keeler	Technical/Electronic Data Specialist, Project Director

External Interfaces:	Yucca Mountain Cooperative Agreement Technical Contact: Jaime Gonzalez
	DOE Technical Task Representative: Jaime Gonzalez

5.0 Standards

For some of the tests that will be used for the investigation ASTM standards have been developed. Wherever such standards are available, they will be followed. They will form the basis for developing implementing procedures.

The following ASTM standards from the *Annual Book of ASTM Standards,* Vol 04.08 will form the basis for the implementing procedures to be followed for rock testing and for analyzing and reporting the results:

ASTM D 2216 Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock.

ASTM D 2664 Standard Test Method for Triaxial Compressive Strength of Undrained Rock Core Specimens Without Pore Pressure Measurements.

ASTM D 2845 Standard Test Method for Laboratory Determination of Pulse Velocities and Ultrasonic Elastic Constants of Rock.

ASTM D 2938 Standard Test Method for Unconfined Compressive Strength of Intact Rock Core Specimens.

ASTM D 3148 Standard Test Method for Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression.

ASTM D 3967 Standard Test Method for Splitting Tensile Strength of Intact Rock Core Specimens.

ASTM D 4341 Standard Test Method for Creep of Cylindrical Hard Rock Core Specimens in Uniaxial Compression.

ASTM D 4405 Standard Test Method for Creep of Cylindrical Soft Rock Core Specimens in Uniaxial Compressions.*

ASTM D 4406 Standard Test Method for Creep of Cylindrical Rock Core Specimens in Triaxial Compression.

ASTM D 4543 Standard Practice for Preparing Rock Core Specimens and Determining Dimensional Shape and Tolerances.

ASTM D 4753 Standard Specification for Evaluating, Selecting, and Specifying Balances and Scales for Uses in Soil, Rock, and Construction Materials Testing.

ASTM D 5079 Standard Practices for Preserving and Transporting Rock Core Samples.

ASTM D 5607 Standard Test Method for Performing Laboratory Direct Shear Strength Tests of Rock Specimens under Constant Normal Stress.

ASTM D 6026 Standard Practice for Using Significant Digits in Calculating and Reporting Geotechnical Test Data.

* It is recognized that this standard is intended for testing soft rock, such as salt and potash, and may be only partially applicable to creep tests on tuff.

The above standards are included in the Annual Book of ASTM Standards, Volume 04.08, Soil and Rock, ASTM, Conshohocken, PA.

Most of the standards include criteria with regard to bias and precision of the results.

To the extent practicable and applicable the implementing procedures also will follow the ISRM Suggested Methods for Rock Characterization, Testing and Monitoring (Brown, 1981). For some tests there are differences between ASTM Standards and ISRM Suggested Methods. Where possible, both will be followed. Where there are unreconcilable differences, the ASTM Standards will be followed, unless we believe the ISRM Suggested Methods to be preferable. In such cases the IP (Implementing Procedure) or SN (Scientific Notebook) will identify the method being implemented, and the justification for the choice.

The following ASTM Standards from the *Annual Book of ASTM Standards* Vol 14.02 will be applied for statistical data analyses and interpretations:

ASTM E 177 Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods

ASTM E 178 Standard Practice for Dealing With Outlying Observations

ASTM E 456 Standard Terminology for Relating to Quality and Statistics

6.0 Implementing Procedures

UCCSN Quality Assurance Procedures that apply to this SIP include:

QAP-C Terms and Definitions

QAP-1.0 Organization

QAP-2.0 Quality Assurance Program - Preparation, Approval, and Revision of Procedures

QAP-2.1 Qualification, Indoctrination, and Training of Personnel

QAP-3.0 Scientific Investigation Control

QAP-3.1 Control of Electronic Data

QAP-3.2 Software Management

QAP-3.3 Models

QAP-3.4 Technical Reports

QAP-3.6 Submittal of Data

QAP-3.7 Qualification of Unqualified Data

QAP-6.0 Document Control

QAP-7.0 Control of Quality-Affecting Procurement and Receipt

QAP-8.0 Identification and Control of Items and Samples

QAP-8.1 Sample Collection includes AP-SII.3Q Rev 1, ICN 0

QAP-8.2 Sample Transfer includes AP-SII.2Q Rev 1, ICN 1

QAP-9.0 Control of Special Processes

QAP-12.0 Control of Measuring and Test Equipment

QAP-16.0 Nonconformance Reports and Trending

QAP-16.1 Stop Work

QAP-17.0 Quality Assurance Records

QAP-18.0 Quality Assurance Auditor Qualification and Conduct of Audits

QAP-18.1 Surveillance

If any of these procedures are replaced by new procedures, or if any new procedures are implemented, they will be added to the procedures applicable to the work planned according to this SIP.

Implementing procedures developed to govern the conduct of repetitive experimental work include:

IPR-012 Preparation of Rock Core Specimens for the Determination of Mechanical Properties of Rock

IPR-010 Splitting (Brazilian) Tensile Strength Test of Rock

IPR-011 Determining Uniaxial Compressive Strength of Rock

IPR-013 Determining Triaxial Strength of Rock

IPR Determining Static Elastic Properties and Strength of Rock in Uniaxial Compression

Implementing Procedures (IP's) have been developed and reviewed in accordance with QAP-2.0, "Quality Assurance Program - Preparation, Approval, and Revision of Procedures."

Existing IP's will be revised to meet current requirements of QAP-2.0.

Tasks that are less routine and less repetitive will be documented in Scientific Notebooks. Scientific Notebooks will be handled in accordance with QAP-3.0 "Scientific Investigation Control." Scientific Notebooks will be used for basic mechanical characterization tests, in addition to the IP's, e.g. in order to document analyses of the results of multiple tests. Scientific Notebooks will be used to document the development and implementation of creep testing procedures and to implement and document the results and analyses of these investigations. Scientific Notebooks will be used to document the development and implementation of numerical analyses, and to document the results.

7.0 Samples

It is expected that some samples may be provided by the project, and that some samples may have to be collected by the investigators. Sample collection, handling, storing, and disposing will be performed in accordance with applicable QA procedures, including UCCSN QAP-8.0 "Identification and Control of Items and Samples", QAP-8.1 "Sample Collection includes AP-SII.3Q Rev 1, ICN 0" and QAP-8.2 "Sample Transfer includes AP-SII.2Q Rev 1, ICN 1".

8.0 Equipment and Instrumentation

Equipment can be classified as:

8.1 Specimen preparation equipment

1) Core drills (V Wilton VSG Twenty Drill Press Model # 2010, Serial # 151102, Milwaukee Dymodrill)

2) Saws (Diamond Rock Saw, HP U 2472275 Rock Saw)

3) Surface grinders (Sharp SG 618 Grinder, Bridgeport Milling Machine)

4) Ovens (Fisher Scientific Isotemp® Model 630F, Fisher Scientific Isotemp®

300 series Model 350 G, Soiltest Cat. No. L-18-A)

5) Specimen dimensions measuring instrumentation (dial gages, calipers)

6) Balances (AND Electronic Balance EP-40KA, American Scientific Products Serial # C0305569; Ohaus Model TP4KD, Serial # 3349)

8.2 Basic mechanical test equipment

1) Splitting Tensile Strength: TQ TecQuipment SM 100 Universal Material Testing Machine

2) Uniaxial Compressive Strength and Static Elastic Properties Measurements: MTS 815 test system with MTS *TestStar™ IIm* control system; MTS pressure intensifier (if desired for measuring lateral displacement); SBEL deformation jacket. LABVIEW (National Instruments) for reading strain gages and for monitoring lateral displacement cylinder

3) Triaxial Strength Testing: MTS 815 test system with MTS *TestStar™ IIm* control system; SBEL or ROCTEST triaxial cell. MTS pressure intensifier system to control confining pressure and monitor lateral displacement; deformation jacket if it is desired to measure the elastic properties during this test

4) Creep testing: MTS 815 test system and/or SBEL test frame. The MTS 815 test system will be a main test system for creep testing. In order to allow proceeding with several creep tests at the same time, we will consider running creep tests in other systems as well. Prime candidates for additional creep test frames are an SBEL test frame, and two other MTS test frames. MTS *TestStar™ IIm* control system. SBEL or ROCTEST triaxial cell for confined test, or to measure lateral displacement using MTS pressure intensifier. LABVIEW (National Instruments) for collecting lateral displacement data, if desired

5) Direct Shear Testing: D.S.M. 50 direct shear testing machine, built by RSG Mfg, Laveen, AZ

6) Miscellaneous load cells, LVDT's, displacement gages and transducers, pressure gages and transducers, thermocouples and data acquisition systems.

All equipment and instrumentation used for quality affecting work will be controlled and calibrated in accordance with QAP-12.0 "Control of Measuring and Test Equipment". Procurement of new equipment and of calibration services will be governed by QAP-7.0 "Control of Quality-Affecting Procurement and Receipt."

1) Acoustic emission monitoring system: to be used to monitor fracture initiation

and propagation

2) Semi-automatic surface grinder: to be used for sample preparation (sample end grinding)

3) Schmidt Hammer: to be used to test rock hardness

4) Ultrasonic velocity measuring system

5) Non-contact optical extensometers: to monitor specimen deformation during uniaxial compression testing, and possibly during Brazilian (direct splitting tensile) and point load testing

9.0 Software and Models

Software to be used during experimental work includes LABVIEW, version 6i, National Instruments, for data acquisition in particular for ultrasonic velocity measurements, strain gage measurements, and cylinder displacement measurements in tests in which the lateral deformation of specimens is monitored by monitoring the oil displacement in a triaxial cell. The MTS system control software, *TestStar™ IIm* will be used during test control set up and for data acquisition for uniaxial, triaxial, and indirect tensile splitting constant strain/stress rate, cyclic testing, and creep testing. Mathcad (Version 3.1, MathSoft Inc.) will be used for data collection and analyses of ultrasonic pulse velocity measurements.

MS Word (Versions 2000 and XP, Microsoft Corporation) and WordPerfect (Version 9, Corel Corporation) software is used for report preparation. Eudora (Versions 4.0, 5.2 and 6.1, Qualcomm Incorporated) and Outlook Express (Version 6.0, Microsoft Corporation) are used for e-mail communications.

MS Access (Versions 2000 and XP, Microsoft Corporation) is being used to handle the literature search database.

MS Excel (Versions 2000 and XP, Microsoft Corporation) will be used for spreadsheet analyses, statistical analysis and graphical data analysis and representation. MATLAB (Version 7.0, The MathWorks, Inc.) will be used for statistical data analysis and for graphical data analysis and representation.

The following software may be used for numerical analysis, in particular for more detailed modeling of experiments: FLAC3D, version 2.0 (http://www.itascacg.com), PFC3D, version 2.0 (http://www.itascacg.com), ANSYS, version 8.0 (http://www.ansys.com) and SAS (http://www.sas.com), version 8.0. If any code is not included in the Software Baseline Report at that time, its use will be in compliance with UCCSN QAP-3.2 “Software Management.” ANSYS will be used for stress/strain analysis of intact rock specimens. FLAC3D will be used for stress/strain analysis in large strain situations, e.g. specimens containing joints. PFC3D will be used to simulate fracturing of rock specimens. SAS will be used for statistical analysis and modeling.

It is possible that a number of routines and/or macros may be developed, depending on the evolving requirements of the project. Any such developments will be performed in compliance with UCCSN QAP-3.2 “Software Management.”

Software will be acquired and qualified in accordance with the requirements specified in UCCSN QAP-3.2 “Software Management.”

Models will be constructed and analyses will be performed in accordance with UCCSN QAP-3.3 “Models.”

10.0 Procurements and Subcontracts

Calibration services will be procured from Bechtel-Nevada, through the Harry Reid Center.

It is not anticipated that subcontractors will be used. If any work were to be subcontracted, it would be handled in accordance with UCCSN QAP-7.0 “control of Quality-Affecting Procurement and Receipt”, and we would notify DOE/YMSCO prior to issuing procurement documents (in accordance with UCCSN QAP-3.0 4.1 b) 11)).

11.0 Hold Points

None planned.

12.0 Quality Control - Accuracy, Precision, Error, and Uncertainty

12.1 Precision, Accuracy, and Representativeness of Results

Precision of experimental results will be estimated, wherever possible, using standard methods for estimating precision (ASTM E 177). It is anticipated, however, that for the main rock tests, constant strain/stress rate tests, and cyclic tests, i.e. long term creep tests, whether on intact rock specimens or on jointed rock specimens, the number of tests that can be completed within the contract time frame is not likely to suffice to allow a formal statistical precision analysis. This is particularly true in light of the large intrinsic variability of the mechanical properties of many tuffs. Methods to estimate precision and accuracy of experimental results will be evaluated as part of the ongoing experimental investigations. “Precision is best described in terms of confidence levels since confidence levels are not only presented in the same units as the variable being measured, but can also be determined through a statistical analysis of the measured data.” (Elliott, 1993, Section 4.2.7.4).

Accuracy for various individual test results will be estimated in accordance with standard error estimating procedures (e.g. Kopchenova and Maron, 1981, Chapter 1, Taylor, 1982, Chapter 3, Section 4.6, Holman, 1994, Sections 3.3, 3.4, 3.5, Bevington and Robinson, 1992, Section 3.2). Representativeness of the work performed will depend largely on the representativeness of samples that can be collected or obtained. Representativeness will be investigated in two ways: by comparing the information about the geology of the specimens tested with that available about potential emplacement horizons, and by comparing mechanical properties obtained in our tests with results obtained previously by others, especially with respect to basic mechanical characterization testing.

12.2 Potential Sources of Errors

Potential sources of error include:

1) Human (operator) error: personnel qualification, indoctrination and training should assist in minimizing the risk of human error. In particular the extensive reviews required by multiple UCCSN QA procedures should assist in catching human errors before they result in the forwarding of erroneous data.

2) Equipment/instrumentation error: calibration should minimize the risk of equipment and/or instrumentation error. The extensive reviews required by multiple UCCSN QA procedures should assist in identifying errors, at least if they are sufficiently serious to be recognizable by a qualified reviewer.

Pells (1993) discusses sources of errors in rock strength tests. The main cause of bias typically is in the sample selection. We have to address this uncertainty by minimizing bias in sample collection, but recognize that this bias often is difficult to avoid. According to Pells (1993) it should be possible to keep load errors with properly calibrated equipment to less than 1%, and strain errors to less than 2%.

Main other sources of error identified by Pells (1993) include specimen preparation errors, i.e. deviations in specimen dimensional requirements. These errors we will strive to minimize by implementing rigorous requirements in the specimen preparation IP, yet we also recognize, based on previous experience with specimen preparation for various tuff types, that meeting specimen preparation requirements for these rocks can be exceedingly difficult, frequently impossible, due to the heterogeneous nature of these rocks, especially the lithophysal ones.

12.3 Uncertainty

The main cause of uncertainty almost certainly will be the intrinsic variability of the rock type(s) tested. We know from experience that the error of most the equipment and instrumentation used is less than 1%, with the probable exception of the measurement of the ultrasonic velocities, where the error can be considerably larger, quite possibly up to 10%. The main approach planned to deal with the uncertainty is to perform a statistically significant number of tests, wherever practical and possible, and estimate any uncertainty based on the results. The main approach to reduce uncertainty induced by instrument and equipment variations will consist of qualified instrument and equipment calibrations.

Uncertainty is introduced by uncontrolled and uncontrollable factors, and by invisible effects, notably the presence of soft inclusions, and sometimes fractures, inside specimens that are not visible on the surface of the samples. We make every effort to identify such weaknesses upon completion of the testing, by inspecting the specimens. Because of the typically extremely brittle failure mode of the tuffs, and the fact that the specimens tend to shatter upon failure, it often is not possible to identify such weaknesses, unless they are truly major.

The issue of representativeness is complex, and introduces an additional uncertainty. We collect samples from horizons that by now are very well known, the source location is precisely known, hence we assume the representativeness issue will be addressed by someone else, because it really is outside the scope of this SIP. While in principle it might be considered desirable to address the representativeness issue more explicitly, e.g. by mineralogical/chemical characterization of tested specimens, such work would expand the scope of the planned work considerably, and therefore has not been included.

We assume that uncertainty induced by human error will be minimized by rigid adherence to QA procedures.

13.0 Data Recording, Reduction, and Reporting

All reduced data will be obtained from, or submitted to, the UCCSN Technical Data Archive (TDA) or the BSC-maintained Technical Data Management System (TDMS). Data will be submitted in accordance with UCCSN QAP-3.6 “Submittal of Data.”

Data will be reported in technical reports, that will be prepared in accordance with UCCSN QAP-3.4 “Technical Reports.”

14.0 Reviews and Verifications

Scientific Notebook reviews will be performed in accordance with QAP-3.0 “Scientific Investigation Control”, especially Sections 4.4.4 “Scientific Notebook Review Requirements.” Numerical investigations will be verified and reviewed in accordance with QAP-3.3 “Models.” Models will be validated in accordance with the requirements in Section 4.2 “Validation of Models” of this QAP. Technical products will be reviewed in accordance with QAP-3.5. All electronic data, when transferred, will be verified in accordance with QAP-3.1 “Control of Electronic Data,” Section 4.4. Those verifications will be documented.

It is not planned to use unqualified data in support of the technical product.

15.0 Records and Submittals

QA records will be produced in compliance with applicable UCCSN QAP's.

QAP-17.0, "Quality Assurance Records" will be implemented for the protection and transmittal of QA records.

Technical reports will be produced in accordance with QAP-3.4, "Technical Reports." QA records to be produced include instrument calibration records, procurement records, data records, Scientific Notebooks, personnel training and qualification records.

QA records in paper form will be stored in one-hour fire protection cabinet. Electronic data will be zipped and then saved into external hard disks. The external hard disks will be identified in accordance with QAP-3.1, "Control of Electronic Data," Section 4.3. The external hard disks will be stored in two rooms located in different buildings. One external hard disk will be locked in the one-hour fire protection cabinet.

Physical access to all QA records is limited to PI and the QA person only. All computers containing QA test results and analyses are password protected.

16.0 References

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