REVIEW COMMENTS ON

STUDY PLAN 8.3.1.15.1.4
LABORATORY DETERMINATION OF THE MECHANICAL PROPERTIES OF FRACTURES

Prepared for

Nuclear Regulatory Commission
Contract NRC-02-93-005

Prepared by

Sui-Min Hsiung
Asadul H. Chowdhury
Amitava Ghosh

Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

March 1995

ABSTRACT

A technical review has been conducted on the Study Plan 8.3.1.15.1.4–Laboratory Determination of the Mechanical Properties of Fractures. This Study Plan has been prepared by the Department of Energy (DOE) to provide a detailed testing plan for obtaining important mechanical properties of fractures in various thermomechanical rock units of the proposed high-level nuclear waste repository at Yucca Mountain (YM), Nevada. The data collected from the investigations proposed in this Study Plan will be used to support relevant design and performance assessment activities. This technical review concentrates on the technical soundness and adequacy of the proposed study to meet the objectives set forth in the Study Plan. Listed below are some concerns and questions raised in this review.

- The discussion regarding the Baseline Study for Vertical fractures is not adequate
- The discussion on the experimental approach for determining the effect of repository environmental parameters on fracture mechanical properties is not complete
- Insufficient effort is made to develop a straightforward methodology for measuring the fracture roughness of samples prepared for rotary shear tests
- The discussion regarding sample preparation is incomplete
- No discussion is provided regarding the use of artificial fractures for testing

CONTENTS

ACKNOWLEDGMENTS

This report was prepared to document work performed by the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the Nuclear Regulatory Commission (NRC) under Contract No. NRC-02-93-005. The activities reported here were performed on behalf of the NRC Office of Nuclear Material Safety and Safeguards (NMSS), Division of Waste Management (DWM). This report is an independent product of the CNWRA and does not necessarily reflect the views or regulatory position of the NRC.

The authors would like to thank W.C. Patrick for his technical review and B. Sagar for the programmatic review of this report. The authors are thankful to R. Sanchez for formatting this report, and to Corky Gray, who provided a full range of expert editorial services in the preparation of the final document.

1 INTRODUCTION

The Study Plan 8.3.1.15.1.4–Laboratory Determination of the Mechanical Properties of Fractures has been prepared by the Department of Energy (DOE) to provide a detailed testing plan for obtaining important mechanical properties of fractures in various thermomechanical rock units of the proposed high-level nuclear waste (HLW) repository at Yucca Mountain (YM), Nevada. A technical review of this Study Plan has been conducted by the Center for Nuclear Waste Regulatory Analyses and is reported here. The purpose of this technical review is to provide an assessment of the adequacy of the proposed study to meet the objectives set forth in the subject Study Plan.

This report documents the concerns resulting from the technical review. The concerns have been presented in a standard format consistent with previous Nuclear Regulatory Commission (NRC) expression of concerns provided to the DOE (NRC, 1989). This standard format includes objections, comments, and questions. The definitions of objections, comments, and questions are given in Section 2 of this report.

2 CATEGORIZATION OF CONCERNS

In this chapter, the major categories of concern used for the review of the Study Plan 8.3.1.15.1.4–Laboratory Determination of the Mechanical Properties of Fractures are summarized. These major categories consist of objections, comments, and questions, and are defined and used consistent with other submittals of concerns from the NRC to DOE in the HLW program.

2.1 OBJECTIONS

An objection is a concern with the DOE program related to either:

(i) Potentially adverse effects on repository performance

(ii) Potentially significant and irreversible/unmitigatable effects on characterization that would physically preclude obtaining information necessary for licensing

(iii) Potentially significant disruption to characterization schedules or sequencing of studies that would substantially reduce the ability of the DOE to obtain information necessary for licensing

(iv) Inadequacies in the Quality Assurance program which must be resolved before work begins

Objections are reserved primarily for concerns with activities, tests, and analyses which, if started, could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual utility of the data for licensing (programmatic fatal flaws). Due to the irreparable nature of activities associated with objections, the NRC would recommend that the DOE not start work until the objections are satisfactorily resolved.

2.2 COMMENTS

A comment is a concern with the DOE program that would result in a significant adverse effect on licensing if not resolved but could not cause irreparable damage if site characterization started before resolution. The DOE program could be modified in the future with some risk to not having the necessary information for licensing; the adverse effects would be primarily related to the program schedule. Therefore, for these concerns, the DOE could start work at its own risk before resolving such concerns with the NRC. The NRC would recommend timely resolution of comments. If resolution is not achieved in a timely manner, comments could be elevated to the higher category of objections described above (i.e., potential significant disruption of schedules that would reduce the ability to obtain information necessary for licensing).

2.3 QUESTIONS

A question is a concern with the presentation of the DOE program such as missing information, level of detail, contradictions, or ambiguities that preclude understanding a part of the DOE program, thereby preventing the staff from being able to comment. The NRC would recommend a timely response by the DOE to such questions. If a question is related to a potential objection, satisfactory resolution

should be accomplished before work begins. If the question is not related to an objection, then the DOE could choose to proceed with work at its own risk and resolve the question in future reports.

3 SPECIFIC CONCERNS

In this chapter, the major areas of concern identified during the review of the Study Plan 8.3.1.15.1.4–Laboratory Determination of the Mechanical Properties of Fractures are summarized. Following the NRC classification of open items in need of resolution in the DOE HLW program, the findings of the review are categorized as Objections, Comments, or Questions. Below, each comment is presented in the format requested by the NRC.

3.1 OBJECTIONS

No concerns of an irreparable nature that would warrant a recommendation that the DOE not start or continue work on the laboratory determination of the mechanical properties of fractures were found during the review of the Study Plan 8.3.1.15.1.4.

3.2 COMMENTS

3.2.1 Section 2.1–General Rationale and Justification

Statement of Concern:

The study plan proposed to conduct "experiments on a set of fractures with the same range of roughness and mismatch to determine the effect of changes in environmental parameters on mechanical properties on both the material type and the surface roughness." No technical criteria for determining nor methods for selecting fractures with the "same range of roughness and mismatch" are provided in the study plan.

Basis:

It is well known that the normal stiffness, shear stiffness, and the surface roughness of a fracture dictate the mechanical behavior of that fracture. These factors will need to be properly controlled so that the effect of changes in environmental parameters (that is, normal stress, saturation, temperature, and time) on mechanical properties can be assessed. In this Study Plan, the control is accomplished by using fractures with the same range of roughness and mismatch for testing. It is, therefore, important to define what constitutes the "same range of roughness and mismatch" and the associated tolerance, if there is any. This definition will assist greatly in achieving the proposed objective, because it will likely dictate the number of samples that ultimately need to be collected for the study of the effect of environmental parameters in order to obtain eight "useful" test data sets for each parameter, as indicated in Section 2.4.3, given that a wide variability of fracture properties is expected.

Recommendations:

Criteria and a method should be provided in this Study Plan regarding the selection of fractures with the "same range of roughness and mismatch."

3.2.2 Section 2.5–Simulation of Repository Environmental Conditions

Statement of Concern:

The study of the effect of changes in environmental parameters on fracture mechanical properties discussed in this section focuses primarily on the TSw2 thermomechanical rock unit. It is not clear why the same study is not planned for other thermomechanical units around the potential repository.

Basis:

Understanding the effect of environmental parameters on fracture mechanical properties for other thermomechanical units should be as important as for the TSw2 unit. The stability of the shafts and ramps appears to be necessary to support the demonstration of compliance with three of the four items in the Issues Hierarchy listed in Section 1.3.2 of this Study Plan.

The discussion provided in the fourth paragraph in Section 2.1 of this Study Plan seems to suggest that the effect of environmental parameters on other rock units will also be investigated.

Recommendations:

A clearly defined scope of work should be provided in the Study Plan. If the investigation of the effect of environmental parameters on other rock units is not included, a justification should be provided.

3.2.3 Section 3.1–Fracture Characterization Studies

Statement of Concern:

The last sentence of the third paragraph in Section 3.1 states that the data for the surface roughness measurements for various natural fractures "will be used to determine the range of roughness for artificial fractures to be tested in the laboratory." It is not clear what the objectives are for testing the artificial fractures or if such testing is part of this Study Plan.

Basis:

Testing of the artificial fractures is not mentioned anywhere in this Study Plan other than in the cited sentence.

Recommendations:

Clarification should be provided if testing of artificial fractures is a part of this Study Plan. If it is, objectives and plans for such testing should be included in this Study Plan. Also needed are the approach, specifications, and procedure to be used for manufacturing the artificial fractures, and the expected correlation of such fractures with natural ones.

3.2.4 Section 3.5.1–Measurement of Fracture Roughness

Statement of Concern:

Discussion regarding the method of measuring fracture roughness of the samples prepared for rotary shear tests is not provided in this Study Plan.

Basis:

Section 3.5.1 of this Study Plan discussed in detail the approach (method) to be used for measuring fracture roughness of samples prepared for direct shear tests. This approach may not be directly applicable to the measurement of fracture roughness for samples prepared for rotary shear tests. It is understood that fracture roughness is a "path dependent" parameter that in turn will affect shear properties of a fracture. Consequently, fracture roughness should be measured along a path parallel to the direction of shear. In this context, measurement of fracture roughness of a hollow sample for rotary shear tests is slightly more complicated than that for direct shear or triaxial compression tests.

Recommendations:

The method for measurement of fracture roughness of samples prepared for rotary shear tests should be provided in this Study Plan.

3.3 QUESTIONS

3.3.1 Section 2.4.1–Sampling in New Core Holes

According to this section, the samples for the proposed Baseline Study will be collected from 6 of the planned 12 core holes suggested as the first phase of the Systematic Drilling Program (Study Plan 8.3.1.4.3.1.1). These samples are primarily for horizontal or near-horizontal fractures. It is not clear how the vertical fractures will be baselined.

Basis:

It is understood that the 12 core holes planned for the Systematic Drilling Program are vertically oriented. These holes may intersect only horizontal or near-horizontal fractures. The probability of getting useful vertical fractures through the Systematic Drilling Program appears to be low. Consequently, the mechanical properties of the vertical fractures may not be adequately baselined from the proposed sampling approach for the Baseline Study.

Recommendations:

The sampling approach in this Study Plan should be revised to (i) assure collection of an adequate number of vertical fractures for the Baseline Study, or (ii) provide justification that the variability of the horizontal fracture properties will span the range anticipated for vertical fracture properties.

3.3.2 Section 3.3.1 Sample Preparation

Statement of Concern:

This section states that the samples to be tested are "machined with the mean fracture plane perpendicular to the cylinder axis." It is not clear whether overcoring is required prior to the machining. Nor is it clear how the fracture samples will be prepared for triaxial compression tests.

Basis:

The sample preparation technique discussed in this section appears to be intended for rotary and direct shear tests for samples that are collected from core holes. The mean fracture planes for these samples are likely to be "substantially" deviated from the plane perpendicular to the cylinder axis of the samples. Such deviation cannot be corrected simply by machining the samples. Consequently, overcoring is likely to be required. This Study Plan does not provide any discussion regarding the need for overcoring. Depending on the original sample cylinder diameter, overcoring may present a problem for the resulting samples to meet the minimum size requirement for the tests, that is, approximately 50.8 mm (2 in.) in diameter. The Systematic Drilling Program (Study Plan 8.3.1.4.3.1.1) currently does not specify the diameter of the core holes to be drilled.

This Study Plan does not provide a discussion of sample preparation technique for possible triaxial compression tests on fractures. "This type of experiment is run on a right-circular cylinder with a nominal length to diameter ratio of 3:1. The fracture being tested is centrally located in the sample, oriented at approximately 30° from the sample axis." No technical difficulty is foreseen in meeting these specifications. However, a discussion of such preparation technique in this section will add to the completeness of this Study Plan.

Recommendation:

Clarification should be provided whether or not an overcoring technique will be used in sample preparation. Discussion regarding the preparation of samples for triaxial compression tests on fractures should be provided.

4 SUMMARY

Study Plan 8.3.1.15.1.4–Laboratory Determination of the Mechanical Properties of Fractures outlines a testing program for obtaining spatial distribution of several important mechanical properties of fractures in various thermomechanical rock units as required to support the relevant repository design and performance assessment activities. The general approach proposed in the Study Plan appears to be reasonable.

However, several areas in the Study Plan have been identified which have not been given sufficient technical considerations and discussions but that may have impact on the success of this Study Plan. For example, this Study Plan does not discuss how the Baseline Study on vertical fractures will be conducted. An adequate number of useful vertical fractures is not likely to be obtained through the proposed Systematic Drilling Program (Study Plan 8.3.1.4.3.1.1). No discussion is given as to what constitutes "the same range of roughness and mismatch." The criteria or methods regarding how to select fractures with the "same range of roughness and mismatch" is important in investigating the effect of environmental parameters on fracture mechanical properties. A detailed discussion of measuring fracture roughness of direct shear test samples is included in the Study Plan. However, such discussion for rotary shear test samples is not provided. This Study Plan provides no discussion concerning a method that may be used if most core samples cannot be machined with the mean fracture plane perpendicular to the cylinder axis, that most likely will occur. Furthermore, this Study Plan seems to indicate that artificial fractures will be used for testing, but no discussion is given regarding the purpose and objectives of such testing.

5 REFERENCES

Nuclear Regulatory Commission. 1989. *NRC Staff Site Characterization Analysis of the Department of Energy's Site Characterization Plan, Yucca Mountain Site, Nevada*. NUREG-1347. Washington, DC: Nuclear Regulatory Commission.

APPENDIX A

DETAILED COMMENTS AND QUESTIONS ON "STUDY PLAN 8.3.1.15.1.4 LABORATORY DETERMINATION OF THE MECHANICAL PROPERTIES OF FRACTURES"

COMMENT 1

The study plan proposed to conduct "experiments on a set of fractures with the same range of roughness and mismatch to determine the effect of changes in environmental parameters on mechanical properties on both the material type and the surface roughness." No technical criteria for determining nor methods for selecting fractures with the "same range of roughness and mismatch" are provided in the study plan.

Basis:

It is well known that the normal stiffness, shear stiffness, and the surface roughness of a fracture dictate the mechanical behavior of that fracture. These factors will need to be properly controlled so that the effect of changes in environmental parameters (that is, normal stress, saturation, temperature, and time) on mechanical properties can be assessed. In this Study Plan, the control is accomplished by using fractures with the same range of roughness and mismatch for testing. It is, therefore, important to define what constitutes the "same range of roughness and mismatch" and the associated tolerance, if there is any. This definition will assist greatly in achieving the proposed objective, because it will likely dictate the number of samples that ultimately need to be collected for the study of the effect of environmental parameters in order to obtain eight "useful" test data sets for each parameter, as indicated in Section 2.4.3, given that a wide variability of fracture properties is expected.

Recommendations:

Criteria and a method should be provided in this Study Plan regarding the selection of fractures with the "same range of roughness and mismatch."

COMMENT 2

The study of the effect of changes in environmental parameters on fracture mechanical properties discussed in this section focuses primarily on the TSw2 thermomechanical rock unit. It is not clear why the same study is not planned for other thermomechanical units around the potential repository.

Basis:

Understanding the effect of environmental parameters on fracture mechanical properties for other thermomechanical units should be as important as for the TSw2 unit. The stability of the shafts and ramps appears to be necessary to support the demonstration of compliance with three of the four items in the Issues Hierarchy listed in Section 1.3.2 of this Study Plan.

The discussion provided in the fourth paragraph in Section 2.1 of this Study Plan seems to suggest that the effect of environmental parameters on other rock units will also be investigated.

Recommendations:

A clearly defined scope of work should be provided in the Study Plan. If the investigation of the effect of environmental parameters on other rock units is not included, a justification should be provided.

COMMENT 3

The last sentence of the third paragraph in Section 3.1 states that the data for the surface roughness measurements for various natural fractures "will be used to determine the range of roughness for artificial fractures to be tested in the laboratory." It is not clear what the objectives are for testing the artificial fractures or if such testing is part of this Study Plan.

Basis:

Testing of the artificial fractures is not mentioned anywhere in this Study Plan other than in the cited sentence.

Recommendations:

Clarification should be provided if testing of artificial fractures is a part of this Study Plan. If it is, objectives and plans for such testing should be included in this Study Plan. Also needed are the approach, specifications, and procedure to be used for manufacturing the artificial fractures, and the expected correlation of such fractures with natural ones.

COMMENT 4

Discussion regarding the method of measuring fracture roughness of the samples prepared for rotary shear tests is not provided in this Study Plan.

Basis:

Section 3.5.1 of this Study Plan discussed in detail the approach (method) to be used for measuring fracture roughness of samples prepared for direct shear tests. This approach may not be directly applicable to the measurement of fracture roughness for samples prepared for rotary shear tests. It is understood that fracture roughness is a "path dependent" parameter that in turn will affect shear properties of a fracture. Consequently, fracture roughness should be measured along a path parallel to the direction of shear. In this context, measurement of fracture roughness of a hollow sample for rotary shear tests is slightly more complicated than that for direct shear or triaxial compression tests.

Recommendations:

The method for measurement of fracture roughness of samples prepared for rotary shear tests should be provided in this Study Plan.

QUESTION 1

According to this section, the samples for the proposed Baseline Study will be collected from 6 of the planned 12 core holes suggested as the first phase of the Systematic Drilling Program (Study Plan 8.3.1.4.3.1.1). These samples are primarily for horizontal or near-horizontal fractures. It is not clear how the vertical fractures will be baselined.

Basis:

It is understood that the 12 core holes planned for the Systematic Drilling Program are vertically oriented. These holes may intersect only horizontal or near-horizontal fractures. The probability of getting useful vertical fractures through the Systematic Drilling Program appears to be low. Consequently, the mechanical properties of the vertical fractures may not be adequately baselined from the proposed sampling approach for the Baseline Study.

Recommendations:

The sampling approach in this Study Plan should be revised to (i) assure collection of an adequate number of vertical fractures for the Baseline Study, or (ii) provide justification that the variability of the horizontal fracture properties will span the range anticipated for vertical fracture properties.

QUESTION 2

This section states that the samples to be tested are "machined with the mean fracture plane perpendicular to the cylinder axis." It is not clear whether overcoring is required prior to the machining. Nor is it clear how the fracture samples will be prepared for triaxial compression tests.

Basis:

The sample preparation technique discussed in this section appears to be intended for rotary and direct shear tests for samples that are collected from core holes. The mean fracture planes for these samples are likely to be "substantially" deviated from the plane perpendicular to the cylinder axis of the samples. Such deviation cannot be corrected simply by machining the samples. Consequently, overcoring is likely to be required. This Study Plan does not provide any discussion regarding the need for overcoring. Depending on the original sample cylinder diameter, overcoring may present a problem for the resulting samples to meet the minimum size requirement for the tests, that is, approximately 50.8 mm (2 in.) in diameter. The Systematic Drilling Program (Study Plan 8.3.1.4.3.1.1) currently does not specify the diameter of the core holes to be drilled.

This Study Plan does not provide a discussion of sample preparation technique for possible triaxial compression tests on fractures. "This type of experiment is run on a right-circular cylinder with a nominal length to diameter ratio of 3:1. The fracture being tested is centrally located in the sample, oriented at approximately 30° from the sample axis." No technical difficulty is foreseen in meeting these specifications. However, a discussion of such preparation technique in this section will add to the completeness of this Study Plan.

Recommendation:

Clarification should be provided whether or not an overcoring technique will be used in sample preparation. Discussion regarding the preparation of samples for triaxial compression tests on fractures should be provided.