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U.S. DEPARTMENT OF ENERGY

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YUCCA MOUNTAIN

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REVIEW RECORD MEMORANDUM

EXPLORATORY SHAFT FACILITY (ESF) TITLE I DESIGN ACCEPTABILITY ANALYSIS AND COMPARATIVE EVALUATION OF ALTERNATIVE ESF LOCATIONS

VOLUME 4

FEBRUARY 3, 1989

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

UNITED STATES DEPARTMENT OF ENERGY
NEVADA OPERATIONS OFFICE/YUCCA MOUNTAIN PROJECT OFFICE

APPENDIX I-6

Technical Assessment Reviews to Assess
Reasonableness and Appropriateness of Data Used in ESF Design

Received w/Ltr Dated 2/9/89

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TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Reviewer: Charles F. Voss   Date: January 28, 1989

Document Reviewed: Appendix B.2 of the ESF Title I Design Summary Report, Volume 4B, "Preliminary Evaluation: Three Dimensional Far-Field Analysis for the Exploratory Shaft Facility."

Summary of the Data Review Process Used in TAR Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (Version 3.0)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 3.0 Reference Information Base

Version 3.0 of the RIB was reviewed as part of the TAR and an assessment was made of the reasonableness of the data. The review was performed by several TAR members based on their technical area of expertise and familiarity with properties of the Yucca Mountain site. Comments concerning the reasonableness of the RIB values are contained in Appendix I.

2. Appropriateness of the data and parameters used in the analyses

The objective of the study was to evaluate the temperatures and stresses at the exploratory shaft locations and in the vicinity of the ESF over a 10,000 year time span. The thermal and mechanical properties used in the analyses were from Version 3.0 of the RIB for the TSw2 unit and are considered appropriate for the analyses.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

The model assumes the welded tuff behaves as a homogeneous, isotropic, linear elastic material. The initial stress state was assumed to be equal to the overburden pressure and horizontal-to-vertical stress ratios of 0.5 and 0.6 for the horizontal stresses. The model does not include the presence of the underground openings, i.e., the stresses and strains reported are due solely to thermal loads and do not account for the stress redistribution that would occur around openings. It is difficult to assess the appropriateness of this conceptual model because of the ambiquity in the stated objective. The model is useful for providing boundary stresses for use in more detailed models of the ESF components (e.g., shaft liner and ESF drifts).

4. Consideration of data uncertainty

The analyses does not consider data uncertainty.

5. Use of the analyses to form conclusions in 8.4

The analyses are not referenced in Section 8.4.

<u>Conclusions:</u>

The material properties, boundary and initial conditions, and the model geometry are consistent with Version 3.0 of the RIB and the ESF Title I Design. The analyses are referenced in the ESF Title I Design Summary Report but the exact use of the results of the analyses is unclear. There is no indication the analyses were used to evaluate whether the ESF design had an impact on the performance objectives.

<u>Recommendations:</u>

The objectives and use of the analyses should be clarified if used to support Title II design. The sections discussing of the results of the analyses should be expanded and focused on design considerations.

11-Jan-1989

Joe R. Tillerson

Joe R. Tillerson

Review of: Bauer, S. J., L. S. Costin, and J. F. Holland, 1988. Preliminary Analyses in Support of In Situ Thermomechanical Investigations, SAND88-2785, Sandia National Laboratories, Albuquerque, NM. (SAIC Ref. No. 3932)

Data Reasonableness

1. The data used in the analyses are, I believe, reasonable for simulating the effects of experiments planned in the ESF at Yucca Mountain.

The data are very closely aligned with the RIB values and the authors have done a very commendable job of making it clear that there was a committment to use RIB values (version 1.001) except where noted because of a desire to simulate the performance of a test proposed for prototype testing in G-tunnel. For each of the three analyses, values were used that make the results reasonable for application to Yucca Mountain hence it is reasonable to use them to estimate responses at Yucca Mountain.

Reasonableness of Analysis Method

1. Considering the available information for the Yucca Mountain site, the level of sophistication of the experiment definition, and the available methods of analysis, I believe that reasonable and adequate analysis methods have been applied to simulate the response of proposed in situ thermomechanical tests.

Conduction heat transfer analyses and linear elastic analyses of the thermomechanical response of 3 ESF experiments are provided. The authors indicate a knowledge of the limitations of the models as applied in these evaluations. It is, in my opinion, commendable that such detailed analyses are available at this stage of experiment design. It is also expected that additional analyses would be conducted as the test definition progresses and as the ESF layout matures.

Treatment of Uncertainty

1. The authors have, in my opinion, recognized some of the uncertainties related to their calculations and have adequately described them. While the report was evidently not intended to be a sensitivity study, the authors stated, and I agree, that "the results of these analyses provide some indication of how the variation of some key geometric and material parameters will affect the predicted results."

The authors recognized the limitations of the two-dimensional nature of the calculations and did multiple crossections in their analyses to attempt to discern the effects of some of their simplifying assumptions. An example of this recognition is in the final paragraph of Section 2.2 and in the discussion of the thermal models in Section 2.3.1. The authors clearly recognized the importance of test separation questions related to the quality of ESF data in their statement in Section 2.3.1 that reads "The results of the thermal analysis ... will be examined carefully to ensure that the access drift is far enough from the heater that its influence on the thermal distribution in the rock is negligible." A good example of the use of analyses to improve experiment design is contained in the final paragraph of Section 3.1 where uncertainties in experiment design parameters (use of insulating blanket with heater, variations in heater power level) were described.

Appropriateness of Analysis use in ESF Title I Design Evaluations

1. I believe that the analyses have been appropriately used in the design evaluations in SCP section 8.4.

The analyses are appropriately summarized in a section that describes analyses that are used to establish the thermal zone of influence for various tests in the ESF. The summary accurately reflects the contents of the report as related to the canister scale heater test, the heated room test, and the thermal stress test. Numbers are quoted from the document related to temperatures, times, and distances from the heaters (e.g. "after 40 months of heating at 100 kW of heater power, temperatures range from 240 C near the heaters to within 5 C of ambient just beyond the access drifts."). The analyses are used to support the statement that from a thermal and mechanical effects perspective, the 30m standoff between ESF and waste emplacement panels appears adequate.

Relative to the canister scale heater test, the analyses indicate the needed standoff from drifts or alcoves, the extent of the thermal zone of influence, and supports the statement that less than 10% changes (relative to in situ conditions) in stress would be expected outside the thermal zone of influence. The thermal zone of influence is rather conservatively defined as being the extent of a 5 C increase above the ambient.

For the thermal stress test, the analyses are used appropriately to support the position that the thermal sone of influence will be 5m horizontally from the drift wall and 7 m vertically from the roof at 90 days, that the stress change outside this zone will be less than 10%, that the 100 C isotherm extends about 1 m, and that stress changes due to mining are likely to extend farther than the thermal zone resulting from the test.

For the heated room test, the analyses are used appropriately to support the position that the thermal zone of influence will extend about 90' from the central drift, that the stress change outside this zone will be less than 10%, and that the 100 C isotherm extends about 7 m horizontally and 10 m vertically from the heater centerline.

Recommendations: None

Science Applications International Corporation

M89-SIDV-ELH-09
WBS: 1.2.5.1
QA Level: I

INTEROFFICE MEMO

DATE: January 24, 1989

TO: J. King

FROM: E. Hardin *EHA*

SUBJECT: Transmittal of revised review for Part I, Element 4 of Technical Assessment Review (TAR) - Design Acceptability Analysis (DAA) for ESF Title I

A signed and dated copy of my review of the report: "NNWSI Exploratory Shaft Site and Construction Method Recommendation Report," by Sharla G. Bertram, (SAND84-1003), is attached to this memorandum. I have incorporated changes from the draft version of this review, to clarify the discussion of the appropriateness of the analytical methods used. These changes are in accord with my original intentions with respect to this review, and are provided to clearly explain and specify my assessment of the Bertram report.

ELH/cvh

cc w/encl:
M. Voegele
A. Matthusen

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TECHNICAL ASSESSMENT REVIEW

PART I, ELEMENT 4 - DATA REASONABLENESS REVIEW

Reviewer: Ernest L. Hardin Signature: ELHardin Date: 1/24/89

Reference: Bertram, S., 1984. "NNWSI Exploratory Shaft Site and Construction Method Recommendation Report," SAND84-1003, Sandia National Laboratories, Albuquerque, NM.

Background: The subject report is referenced in SCP Section 8.4 with respect to ESF location, and selection of a method for excavating the shafts. This review pertains only to the exploratory shaft location analysis. The subject report actually addresses two problems relevant to ESF location: (1) screening of the exploration block for preferred areas where shafts could be located, and (2) selection of one of these areas as the recommended location (without specifying an exact position within the area selected). The purpose of this review is to examine the reasonableness of the site-specific data, and the manner of its use in the two-step screening and selection process, particularly in light of geologic data which have been published since release of the Bertram (1984) report.

The term "exploration block" is used throughout this review in the same manner as in the subject report, referring to an area that is approximately the same as the repository block defined in the Yucca Mountain Environmental Assessment, Chapter 3.

1. Reasonableness of the parameter values in the V. 3.0 RIB

None of the information identified below as data used in the subject report, is represented in the RIB Version 3.0.

2. Appropriateness of the data and parameters used in the analyses

As stated in the Introduction to the subject report, the data made available to the Ad Hoc Technical Oversight Committee (responsible for the screening and selection) were preliminary and unpublished at the time the analysis was done, so the information was incorporated into the report without reference. In addition, the report states that some of the information in the report may be refined with respect to that used by the committee, but without incurring changes significant enough to alter the recommendations produced. The review comments given below support this statement.

Screening and selection made use of the following types of site specific data:

1) location, extent, and projected subsurface dip of potentially adverse structures and bounding structures;

2) extent of fracturing associated with structures such as those bounding the exploration block;

3) topography; and

4) information on vertical thickness of target units.

The manner of use of each of these types of data was such that the recommendations of the selection process were robust with respect to the associated data uncertainty. For area screening, the data were used to support assessment of appropriate setback distances from identified structures. For location selection, the data were used mainly as the basis for relative numeric ranking of preferred areas with respect to specific subcriteria, in a figure-of-merit type exercise.

Topographic maps and geologic maps of surface faulting are reproduced directly in the report. For items 1), 2) and 4) above, available knowledge of structures, the variability of fracturing, and unit thickness was used in the analysis, but all of the data actually used were not explicitly presented in the subject report. As discussed below, enough information was provided for an assessment that the data used are reasonable, and were used appropriately.

The location and extent of each fault represented on Figure 2 of the subject report is consistent with the geologic map of Scott and Bonk (1984), and is generally consistent with the major faults mapped by Swadley et al., (1984). In particular the subject report is consistent with the representation by Scott and Bonk (1984) of en echelon minor faults. Setback distances used in the area screening are referred from the mapped boundaries of such zones, and are greater at the southern and eastern boundaries to allow for the possible unmapped extension of such zones into the exploration block. This constitutes appropriate use of the data available.

The steep westward dip of the Ghost Dance fault within the exploration block, as represented in Figure 2 of the subject report, is approximately the same as the values reported by Scott and Bonk (1984). Similarly, the dips represented for other faults are consistent with the more recently published information. Minimum setback distances to the different bounding structures that were used for screening preferred areas, are reasonable given the uncertainty inherent to the fault dip information obtained from surface mapping.

The extent of fracturing associated with each bounding structure and potentially adverse structure was estimated for the purpose of area screening. Specific data are unavailable for the variability of fracturing in the Topopah Spring Member, the Calico Hills unit, or any other unit that is substantially buried within the exploration block. However, outcrops of the Tiva Canyon Member caprock have been mapped, and less dense fracturing was found at locations in the interior of the exploration block versus near the margins (see USGS, 1984, Figure 37). The setback distances used for bounding and potentially adverse structures are generally consistent with observed trends in fracturing of the caprock, and are appropriate for the Topopah Spring Member and repository horizon to the extent that trends in fracturing of this unit are similar to those in the caprock.

One of the recommendations of the selection study was that additional geologic data be acquired for the five preferred areas in the exploration block. A letter report was subsequently submitted by the USGS to the DOE, containing additional geologic information on the three highest-ranked areas (Dixon to Vieth, 1982). The report tends to support the data set used in the original selection, confirming the location and known characteristics of mapped faults. However, the letter report also states:

> "Recognition of small displacement faults in thick ash-flow cooling units is difficult...because the boundaries between intra-cooling unit zone boundaries are gradational....Faults with smaller displacements must be recognized by traces of breccia, gouge, or slickensides along the surface. Such small faults, however, commonly anastomose, die out in a fan of fractures, and reappear at different locations within short horizontal distances....along a very sharp zone boundary, 'micro' faults that otherwise appear to be fractures commonly record a few centimeters of displacement. In the absence of a very sharp zone boundary at [Bertram (1984) preferred areas 4, 3, and 5], numerous 'micro' faults of this nature probably exist undetected..."

As stated, the extent, persistence, and the attendant fracturing associated with these "micro" faults is less than for the throughgoing mapped faults. It is likely that the frequency of "micro" faults is correlated with the location of throughgoing faults. The setback distances used in the original preferred area screening process (minimum of 1000 feet from mapped faults) therefore serve to avoid many such "micro" faults. Two "micro" faults were observed on the walls of Coyote Wash in the vicinity of the planned ESF location. The intersection of such features with the shafts or a few of the ESF drifts may be expected. The impact of such intersections on testing in the ESF will be insignificant because: (1) significant faulting is likely to be recognized from geologic mapping, and (2) sensitive tests can be located outside the influence of such faulting. The impact of such intersections on waste isolation performance of the site is likely to be much less significant than intersection at the main test level with major structures that are the objective of long lateral drifts. The data used in the original area screening were therefore appropriate and reasonably complete although "micro" faults were not considered explicitly.

In conclusion, the data used in the subject report are consistent with other published information, and were used appropriately. In some cases (e.g., fault dip) the data actually used must be inferred from maps of areas excluded in the screening process. Any uncertainty associated with such inference is not significant because of the generality and robustness of the screening and selection methodologies used. Small "micro" faults are evident from further mapping at three of the preferred areas, however, intersection of such features with the ESF underground openings is unlikely to significantly impact either site characterization, or the waste isolation performance of the site.

3. Appropriateness of the conceptual models used in the analyses, and apppropriateness of the analytical method(s) used

The screening analysis related the incidence of potentially adverse constructability conditions, and of conditions not typical of the overall exploration block, to proximity to faults and fault-like features mapped at the surface. Adoption of setback distances to avoid fractures associated with these features, is consistent with observed trends in fracturing of the Tiva Canyon cap rock as mentioned above. Dip measurements at the surface were extrapolated downward; this practice is appropriate when used in conjunction with conservatively large setback distances, which were applied in all directions from the subsurface projection of each structure.

Bounding structures for the exploration block were identified from mapped structures. The structural significance of Drill Hole Wash was not well understood because it is probably an old, strike-slip fault that does not exhibit readily identifiable surface characteristics. Because the full extent of Drill Hole Wash was not mapped as a fault (see Scott and Bonk, 1984) it was not considered bounding in the same way as the other structures, but was designated a potentially bounding structure that may control expansion of the repository to the north. Accordingly, as stated in the subject report, proximity to Drill Hole Wash was incorporated implicitly along with proximity to potentially adverse structures, as a desired attribute of the ESF location in the selection process.

In the ESF location selection process, the occurrence of material that could cause squeezing ground conditions was assumed to be associated with faulting. Various drillholes have been constructed at Yucca Mountain, and none have encountered high stress or instability that would suggest squeezing ground conditions could occur in the ESF. Potentially incompetent material exists in the tuff section, as thin (up to about one meter) smectite-enriched layers near the base of the Tiva Canyon Member (Bish and Vaniman, 1985), and possibly near the top of the basal vitrophyre of the Topopah Spring Member. Even if these layers were demonstrated to be significant with respect ESF stability, they are laterally contiguous and therefore non-discriminating for ESF locations within the exploration block. Similar altered material has also been observed in distributed concentrations near major structures such as Drill Hole Wash and Yucca Wash (Bish and Vaniman, 1985). Avoidance of such concentrations is addressed by the setback criteria used in the analysis.

The location selection process treated the potential for flash flooding by means of a qualitative evaluation of the topography at each of the five preferred areas. The stated purpose for considering flooding potential was engineering related: to locate the ESF where flooding could not occur, or could be accommodated economically. Although the flooding potential of the preferred areas was informally ranked in the subject report, every such area lies outside the Regional Maximum Flood Area identified in a more recent, quantitative study of flood prone areas at Yucca Mountain (Squires and Young, 1984). The consideration of flooding potential relative to the other preferred areas was thus appropriate, and consistent with the information developed by the later study.

The methodology used for screening the exploration block for preferred areas is probably consistent with meeting repository performance requirements. Although postclosure and preclosure repository performance considerations were not explicitly incorporated into the methodology, the criteria considered tended to be discriminating with respect to major performance-related concerns. For example, setback distances from bounding and potentially adverse structures, and the exclusion of adverse topography, helped to ensure that the facility will be sited in the most suitable rock. The distance-to-adverse-structures criterion also enhances the representativeness of the site characterization program. Repeating the screening process using another set of criteria that explicitly consider waste isolation concerns could produce different preferred locations. However, in the judgement of this reviewer such a reiteration would not be yield a significantly different range of areas, nor any areas that are more suitable based on available site specific information, than the five preferred areas identified in the subject report.

The Figure of Merit process for selecting a location from the five preferred areas tended not to consider potential impacts on waste isolation from ESF construction and testing activities. The criteria used for location selection tended to be non-discriminating with respect to some waste isolation concerns, particularly hydrologic factors such as site conditions contributing to locally greater moisture flux. This is perhaps the only significant shortcoming in the analyses documented by the subject report.

Lateral variability of the vertical thickness of the target rock units was relatively non-discriminating in the location selection process, based on information from available drillholes. Drillhole data indicate that the Topopah Spring Member and the Calico Hills unit (the two principal unsaturated units considered in the subject report) are relatively thick throughout the exploration block (Ortiz et al., 1985). Whereas unit thickness was relatively non-discriminating, lateral facies variation within lithostratigraphic units was not considered, and might have been discriminating if considered in conjunction with selection criteria that explicitly incorporated waste isolation concerns.

In summary, the conceptual basis and the analysis methods used for area screening and location selection as documented in the subject report were appropriate, with one exception. For the location selection process, waste isolation concerns such as flux variability and lateral facies variation were not considered explicitly, and tended to be weakly addressed by the factors that were used. Although waste isolation was not an explicit concern of the area screening process, the factors considered in this step did discriminate with respect to major waste isolation concerns.

4. How data uncertainty was considered

Data uncertainty was addressed by using conservative setback distances, to account for uncertainty in the nature of potentially adverse conditions adjacent to structures, and in the dip of such structures. These distances were increased to account for relative uncertainty with respect to the characteristics of some structures. Also, data uncertainty was considered by recognizing that Drill Hole Wash was a potentially bounding structure, and including capability to explore this feature as an attribute in the location selection process. Uncertainty in the qualitative evaluation of the flash flooding potential was accommodated by using conservative estimates of the relative flooding potential at each of the five preferred areas.

5. Use of the analyses to form conclusions in Section 8.4

The subject report is referenced in 8.4.2.1.5.2 (Representativeness of the

ESF location), and in 8.4.2.3.3.1 (Introduction to the description of the ESF). The latter section gives a synopsis of the subject report without commentary, describing the analyses contained in the report in the context of an initial contribution to the basis for the current ESF location and construction method. The former SCP section states that borehole USW G-4 was sited with the intention of evaluating conditions at the ESF location, and that the results were consistent with expected lithostratigraphic and structural conditions, which comprised part of the basis for the location selection. SCP Section 8.4 develops a position that the planned ESF and its location are acceptable with respect to potential impacts on repository performance, therefore the shortcoming in the subject report that is identified in part 3 above does not impact the manner in which the report is used in 8.4.

Recommendations: Location selection should be reviewed with respect to potential impacts on waste isolation performance of the site. This is underway as part of the ongoing Design Acceptability Analysis.

References

Bish, D. L. and D. T. Vaniman, (1985), Mineralogic Summary of Yucca Mountain, Nevada: Los Alamos National Laboratory report LA-10543-MS, issued October 1985.

Dixon to Vieth, (1982), letter: G. L. Dixon, (USGS/ Las Vegas) to D. L. Vieth (DOE/NV-WMPO), re: "Results of detailed geologic mapping at the five potential exploratory shaft locations on Yucca Mountain," July 16, 1982.

Ortiz, T. S., R. L. Williams, F. B. Nimick, B. C. Whittet, and D. L. South, (1985), A three-dimensional model of reference thermal/mechnical and hydrological stratigraphy at Yucca Mountain, southern Nevada: Sandia National Laboratories report SAND84-1076.

Scott, R. B. and J. Bonk, (1984), Preliminary geologic map of Yucca Mountain with geologic sections, Nye County, Nevada: U.S. Geological Survey Open File Report 84-494, scale 1:12,000.

Scott, R. B. and M. Castellanos, (1984), Stratigraphic and structural relations of volcanic rocks in drillholes USW GU-3 and USW G-3, Yucca Mountain, Nye County, Nevada: U.S. Geological Survey Open File Report 84-491.

Squires, R. R. and R. L. Young, (1984), Flood potential of Fortymile Wash and its principal tributaries, Nevada Test Site, Southern Nevada: U.S. Geological Survey, Water Resources Investigations Report 83-4001.

Swadley, W. C., D. L. Hoover, and J. N. Rosholt, (1984), Preliminary report on Late Cenozoic faulting and stratigraphy in the vicinity of Yucca Mountain, Nye County, Nevada: U.S. Geological Survey Open File Report 84-788.

USGS, 1984, A summary of geologic studies through January 1, 1983, of a potential high-level radioactive waste repository site at Yucca Mountain, southern Nye County, Nevada: U.S. Geological Survey Open File Report 84-792.

TECHNICAL ASSESSMENT REVIEW
Reviewer: Paul L. Cloke
Field: Geochemistry

PART I - ELEMENT 4

Reference: Birgersson, L, and Neretnieks, I., 1982. Diffusion in the Matrix of Granitic Rock. Field Test in the Stripa Mine, Scientific Basis for Radioactive Waste Isolation.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objective of this review is to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The overall evaluation process considers the following:

1. the reasonableness of the data in the RIB (Version 03.001)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

This portion of the overall review of this reference considers only items 1 through 4, above, and is restricted to geochemical data and concerns.

1. Reasonableness of the parameter values in Version 03.001 Reference Information Base

This version of the RIB contains no geochemical data relevant to the subject of this paper.

2. Appropriateness of the data and parameters used in the analyses

This reviewer has no concerns over the intent of the paper or its application to movement and diffusion of tracers in the granite in the saturated zone of the Stripa mine. The diffusivity in the Stripa granite was taken from the literature and was not determined by modeling the experimental data. However, some of the measured results are consistent with results of modeling using the literature values. In this reviewer's opinion this paper is inappropriate for this application to the NNWSI Project because of the great differences between the Stripa mine and Yucca Mountain. I discussed this with Edward Norris (LANL) who concurred and stated that in conjunction with the study plan for tracers LANL had used TRACR3D and appropriate input data to estimate the diffusion. They obtained only about 8 cm penetration, as compared to the 30 estimated in the SCP. Results of this analysis have been written up by K. Birdsell (LANL), reviewed, and approved for publication.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used.

Irrelevant. The data are inappropriate for the Yucca Mountain site.

4. Consideration of data uncertainty.

Irrelevant.

5. Use of the analyses to form conclusions in 8.4

The analyses were used to support limited diffusion of the geochemical alteration zone caused by grout emplaced in the ESF.

6. Impacts.

In view of the discussion with Edward Norris (LANL), noted above, there appears to be no impact.

Without any basis for comparison of the very different circumstances at the Stripa Mine and Yucca Mountain an assessment of the impact would not have been possible.

Conclusions: This reference is inappropriate for the conclusion drawn. It is suggested that the author of this section of the SCP (Section 8.4.2.3.6.1) inadvertantly referenced the wrong document.

Recommendations: A proper reference, such as to Birdsell's paper, should be made in a progress report for the SCP and alteration due to diffusion from emplacement of grout reevaluated. Because the value used appears to be conservative and because even ten times deeper penetration would not significantly affect ESF tests, the representativeness of the tests, or the repository performance, this reevaluation need not be done prior to starting ESF construction. However, it should be performed prior to emplacing grout in or within about 30 m of test areas.

Paul J. Cloke 1/25/89

Title: "Preliminary Calculations of the Effects of Air and Liquid Water-Drilling on Moisture Conditions in Unsaturated Rocks" , LBL-25073

Authors: G. S. Bodvarsson, A. Niemi, A. Spencer and M. P. Attanyake

Date of Review: Dec. 27, 1988

Reviewer: Edward M. Kwicklis, U. S. Geological Survey

Statement on Data Reasonableness:

The data utilized in LBL-25073 are believed to be reasonable for use in numerical simulations intended to examine the effects of drilling-induced moisture perturbations in and around the Exploratory Shaft Facility. Matrix moisture retention curves determined either by the USGS (using mercury porosimetry) or by Sandia National Lab (using psychrometers) were employed in these simulations. Relative permeability versus saturation curves were predicted theoretically from the measured moisture-retention curves using the method of Mualem (1976), as implemented by van Genuchten (1978). While no data has been collected regarding the dependence of relative permeability on saturation in welded tuff, the two moisture retention curves used to predict this relationship are quite dissimilar, and yet similar results regarding depth of water penetration in the matrix and moisture redistribution patterns were obtained. This implies that the numerical results, as well as the conclusions drawn from them (especially regarding the extent of matrix wetting and matrix moisture redistribution), are not particularly sensitive to the moisture characteristic curves or to the ability of the van Genuchten expression to predict the relative conductivity of the welded tuff matrix.

Predicted extent of water movement within the fracture, and water redistribution from the fracture into the matrix after drilling has ceased, did not appear to be particularly sensitive to the unsaturated hydraulic characteristics assumed for the fracture. In any case, the highly transient phenomena such as water movement down a fracture, are of secondary importance; a more fundamental concern is the length of time required for the fracture to return to its initial moisture state. For both sets of assumed fracture characteristics, this time period was on the order of minutes or hours.

Statement on Reasonableness of Analysis Method

The method of analysis used by the authors of LBL-25073 is believed to be an appropriate means of examining the changes in the natural moisture state of welded tuff caused by drilling with water or air. The authors used a numerical model capable of simulating the simultaneous movement of air and water. Aperture variation within the fracture was accounted for by assuming that the permeability and water potential within the fracture were functions of the fracture saturation. By explicitly partitioning the flow domain into distinct fracture and matrix domains, rather than considering the rock as a composite porosity medium, the authors were able to simulate the highly transient fluid exchange processes between fractures and adjacent matrix, both during the drilling period and during the recovery period.

Statement on the Treatment of Uncertainty

The authors treated uncertainty by assuming two quite dissimilar sets of unsaturated hydraulic properties for both the fracture and the matrix pore-domains. In both cases, the simulated response to drilling with water, and the conclusions that could be drawn from the simulations were quite similar.

Because the governing partial differential equations were solved numerically, the solutions are only approximate solutions, the accuracy of which is uncertain. Discretization of the time and space domains introduces some unknown error. This uncertainty was examined by varying the mesh spacing, and weighting method used to estimate the intercell conductances. Mesh effects were most pronounced during the highly transient drilling period, which as previously mentioned, is considered to be of less importance than the long term effects considered in the redistribution period.

The simulations considered both horizontal and vertical fracture orientations, and the effects of drilling both with water and with air. The air used in the simulations was assumed to be near-saturated with water. If the air had been assumed to be dry, one would expect that more extensive drying of the matrix blocks may have been predicted. This scenario was not considered in this study. However, it is possible that even if air with low relative humidity were passed over the surfaces of the matrix blocks, water loss from the matrix would quickly decrease as the outer few centimeters of the block dryed, and the permeability in this region decreased. Such phenomenon would be similar to evaporation from a bare soil, where actual evaporation is less than the potential evaporation, because the capacity of the soil to transmit water decreases as it begins to dry out.

Statement on Appropriateness of the Use of the Analysis

The results of Bodvarsson et al. (1988) were correctly summarized on SCP 8.4.3-15. I believe that the analysis was appropriately used to support the conclusion that changes in matrix saturation due to invasion by drilling fluids could be expected to be small, and that near-equilibrium conditions within the matrix could be re-established within weeks to months after drilling had ceased. The observation by Bodvarsson et al. (1988) that water introduced into the fracture during drilling would be quickly (hours to days) imbibed by the matrix after drilling had ceased was also appropriately used to support the conclusion that large changes in saturation would probably not occur in fractured, welded tuff as a result of drilling with liquid.

This reviewer does not necessarily agree with the conclusion stated on SCP 8.4.3-16 that for the nonwelded tuff matrix, the return to near initial conditions would be shorter than that predicted for the welded tuff matrix because of the higher permeability of the nonwelded unit. Because of its higher permeability, the nonwelded units will accept far more water than the welded unts, saturating a far larger area around a borehole. Hence, although the permeability of the nonwelded unit is higher, there is also a far larger volume of water that must be re-distributed. Therefore, it is not intuitively clear whether re-equilibration time will be longer or shorter for non-welded tuff.

In addition, the numerical simulations are limited in that they did not consider contamination of in situ water by drilling fluids, a circumstance that may complicate considerably the interpretation of chemical analysis performed on water samples taken from the unsaturated zone. Nor did the simulations consider the possibility that finely ground tuff particles produced during drilling might be washed down fractures by the drilling fluid and filtered out as water is imbibed along the fracture-matrix interface, thereby altering the nature of subsequent fracture-matrix interactions. These interactions may be a concern in some hydrologic studies.

<u>References:</u>

Mualem, Y. 1976. " A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Media," Water Resources Research 12(3):513-522.

Van Genuchten, R. 1978. "Calculating the Unsaturated Hydraulic Conductivity with a New Closed Form Analytical Model," Water Resources Bulletin, Princeton University Press, Princeton University, Princeton, New Jersey.

Edward M. Kunkle 1-23-89

UNSOLICITED COMMENT THAT COULD BE ADDED TO
TECHNICAL ASSESSMENT REVIEW
Reviewer: Paul L. Cloke
Field: Geochemistry

PART I - ELEMENT 4

Reference: Bodvarsson, et al., 1988

Summary of the Data Review Process Used in TAR Part I - Element 4

The objective of this review is to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The overall evaluation process considers the following:

1. the reasonableness of the data in the RIB (Version 03.001)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 03.001 Reference Information Base

2. Appropriateness of the data and parameters used in the analyses

{Copy of paper not examined}

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used.

4. Consideration of data uncertainty.

5. Use of the analyses to form conclusions in 8.4

Conclusions: The very small change in the water saturation of the tuff due to air drilling implies that no significant change to the water chemistry will occur as a consequence of evaporative concentration—during drilling. Thus, it indicates that this potential source of an impact on the site with respect to the NRC concerns has been appropriately addressed.

Recommendations: Add somewhere as you see fit.

Paul L. Cloke 1/23/88

Title: Preliminary Scoping Calculations of Hydrothermal Flow in Variably Saturated, Fractured, Welded Tuff During the Engineered Barrier Design Test at the Yucca Mountain Exploratory Shaft Test Site

Authors: Thomas Buscheck and John Nitao

Date of Review: Jan. 3, 1989

Reviewer: Edward Kwicklis, U. S. Geological Survey

Statement on Data Reasonableness:

The data utilized in this report are believed to be reasonable for use in numerical simulations intended to investigate the possible magnitude and spatial extent of changes to the hydrologic, pneumatic and thermal conditions during the Engineered Barrier Design Test (EBDT).

Matrix hydrologic properties used in the simulations are those measured for sample G4-6 (a sample of Topopah Springs tuff cored at a depth of 1158 feet within the repository interval at Yucca Mt.) This sample was determined by Peters et al. (1984) to be "representative" of the hydrolgeologic unit at the repository horizon. Because no direct measuremnents have been made to define the relationship between effective conductivity and pressure head for densely welded tuff, it was necessary to estimate this relationship using the method of Mualem (1976), as adapted by van Genuchten (1978). The relationship between hydraulic conductivity and pressure potential in the matrix is therefore subject to some uncertainty.

An equivalent hydraulic aperture of 100 microns, and an average fracture spacing of 0.3 meters, were assumed to be representative values for the fractures in these simulations. The assumed fracture spacing compares well with estimates of vertical fracture spacing (0.22 meters) and horizontal fracture spacing (0.48 meters), calculated by Wang and Narasimhan (1985) from data collected from USW-G4. Estimates of average equivalent hydraulic aperture for the Topoaph Srings have ranged from 4.5 microns (Peters et al., 1986) to 310 microns (Wang and Narasimhan, 1985). The equivalent hydraulic aperture assumed by Buschek and Nitao (1988) (100 microns) falls within this range. The unsaturated hydraulic properties used by Buschek and Nitao (1988) for the 100 micron fracture were originally developed by Wang and Narasimhan (1986) for a fracture having an equivalent hydraulic aperture of 116 microns. These properties may be reasonable, but the validity of the assumed unsaturated flow properties is as yet unproven.

Thermal properties assumned for the rock matrix by Buscheck and Nitao (1988) compare well with thermal properties listed in the Reference Information Base (RIB). The values assumed by Buschek and Nitao (1988) for saturated thermal conductivity (2.34 W/m^{o}K), dry thermal conductivity (1.74 W/m^{o}K), and dry thermal capacitance (2.17 J/cm^{3}, calculated as specific heat of the rock (840.0 J/kg^{o}K), multiplied by the density of the rock (2580 kg/m^{3})), fall within the ranges of saturated thermal conductivity (2.29 +/- 0.17 W/m^{o}K), dry thermal conductivity (1.88 +/- 0.25 W/m^{o}K) and dry thermal capacitance (2.17 J/cm^{3}-^{o}K) listed in the RIB.

<u>Statement on the Reasonableness of Analysis Method</u>

The analysis method employed in this report is believed to be an appropriate means of examining the extent to which variably saturated, fractured rock surrounding a heat source will respond hydrothermally to heating and subsequent cooling. The modified version of the numerical code TOUGH (Preuss, 1985) employed in this analysis is capable of modeling the coupled transport of liquid water, water vapor, air and head in fractured porous media. By explicity partitioning the flow domain into distinct fracture and matrix domains, rather than considering the rock as a composite porous media, the authors were able to illustrate the distinct roles that the fractures and matrix could each be expected to play as the region surrounding a heat source begins to dry out.

Statement on Treatment of Uncertainty

In their summary statements, the authors acknowledged the need for a sensitivity analysis of the model results to model input parameters. However, in this particular report, I do not feel that the authors in any way considered the uncertainty associated with the model parameters employed in these simulations. The stated purpose of the numerical modeling described in this report was to investigate the spatial and temporal changes in temperature, pressure and saturation, as well as the ranges of these properties, that could be expected to occur in the area around heaters emplaced as part of the EBDT. The model results could then serve as a guide for the design of the monitoring network, as well as heater location and spacing. The authors need to be cautious about drawing any conclusions from modeling based on one set of model input parameters.

Statement on Appropriateness of the Use of the Analysis

The analysis was, in my opinion, appropriately used in SCP section 8.4 (8.4.2-143) to support the statement that during the EBDT, the thermally disturbed zone would extend approximately 10 meters from the heater centerline, and that within the thermally altered zone, the 100 °C isotherm will be a maximum of approximately 2 meters readially from the cetnerline of the heater. In the absence of a parameter sensitivity analysis, these results are somewhat uncertain. However, as the authors pointed out, the assumption of an infinitely long heater string (which allows them to assume symmetry boundaries along the midplane of the fracture and the midplane of the matrix block) probably causes the radial extent of the thermally disturbed zone to be overestimated by the numerical model. The predictions therefore should tend to be conservative if one is interested primarily in the spatial extent of thermal or hydrologic disturbance to the in situ conditions caused by the presence of the heater, or to interference between the heater units.

References:

Mualem, Y. 1976. "A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Media", Water Resources Research 12(3):513-522.

Peters, R. R., E. A. Klavetter, I. J. Hall, S. C. Blair, P. R. Heller, G. W. Gee. 1984. "Fracture and Matrix Hydrologic Characteristics of Tuffaceous Materials From Yucca Mountain, Nye County, Nevada, SAND84-1471, Sandia National Laboratories, Albuquerque, New Mexico.

Peters, R. R., J. H. Gauthier, and A. L. Dudley. 1986. " The Effect of Percolation Rate on Water-Travel Time in Deep, Partially Saturated Zones", SAND85-0854C, Sandia National Laboratories, Albuquerque, N. M.

Preuss, K. 1985. "TOUGH User's Guide", LBL-20700, Lawrence Berkeley Laboratory, Berkeley, CA.

Van Genuchten, R. 1978. "Calculating the Unsaturated Hydraulic Conductivity with a New Closed Form Analytical Model", Water Resources Bulletin, Princeton University Press, Princeton University, Princeton, New Jersey.

Wang, S. Y., and T. N. Narasimhan. 1985. "Hydrologic Mechanisms Governing Fluid Flow in Partially Saturated Fluid Flow in Fractured, Porous Tuff at Yucca Mountain", SAND84-7202, Sandia National Laboratories, Albuqueque, N. M.

Wang, S. Y., and T. N. Narasimhan. 1986. "Hydrologic Mechanisms Governing Partially Saturated Fluid Flow in Fractured Welded Units and Porous Non-Welded Units at Yucca Mountain", SAND85-7114, Sandia National Laboratories, Albuqueque, N. M.

Edward M. Kendlin 1-23-89

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Reviewer: Charles F. Voss Date: January 20, 1989

Charles F. Voss 12/20/89

Document Reviewed: Case, J.B. and P.C. Kelsall, 1987. "Modification of Rc Mass Permeability in the Zone Surrounding a Shaft in Fractured, Welded Tuff SAND86-7001, Sandia National Laboratories, Albuquerque, NM.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (Version 3.0)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 3.0 Reference Information Base (RIB)

Version 3.0 of the RIB was reviewed as part of the TAR and an assessment was made of the reasonableness of the data. The review was performed by several TAR members based on their technical area of expertise and familiarity with properties of the Yucca Mountain site. Comments concerning the reasonableness of the RIB values are contained in the review of the RIB included in Appendix I.

2. Appropriateness of the data and parameters used in the analyses

The stated objective of the report is to provide a model of the modified permeability zone (MPZ) around a shaft in a fractured welded tuff of the Topopah Spring unit for use in performance analyses of the repository. Blast damage during construction and stress redistribution in the rock surrounding the shaft are the two mechanisms considered that may influence the MPZ. The data used in the analyses are believed to be reasonable based on a comparison with values in the RIB and my understanding of the laboratory measurements made on tuff from the Yucca Mountain site.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

The logic used to develop the conceptual model of the modified permeability zone is based on case history studies (especially in the case of blast damage assessment) and on laboratory and field experiments. I consider the process that was used and the associated simplifying assumptions to be reasonable and appropriate based on the current understanding of mechanical-hydrologic behavior of tuff and the stated objective of the report.

4. Consideration of data uncertainty

The analyses considered ranges of expected parameter values. In some cases, the range used is smaller than the range given in the RIB. However, because the analyses are intended to represent the overall or averaged response of the rock mass around the shaft and not the worst possible conditions at a point location, the ranges used are considered appropriate. Data uncertainty was considered by (1) including worst case assessments using bounding values, and (2) the use of conservative assumptions when alternative interpretations were available.

5. Use of the analyses to form conclusions in 8.4

Section 8.4.3.2.3.1 appears to overstate the degree of conservatism in the MPZ models developed by Case and Kelsall. On page 8.4.3-25 of the SCP, it is stated that "They [Case and Kelsall] concluded that the models developed for the MPZ are conservative in that they overestimate the change in the hydraulic conductivity of the rock mass surrounding the shaft." However, on page 17 of the reference document, the statement appears "These assumptions [contained in MPZ model] are conservative for the isotropic state of stress (i.e., they tend to over-predict increases in permeability) in that stress increases across some fractures are ignored and each fracture is, in effect, assumed to be perpendicular to the direction of maximum stress relief. Conversely, the simplified analysis does not account for the effects of shearing along fractures. On balance, it is the author's judgement that the model is a reasonable representation of permeability changes in fractured welded tuff.

A related concern, although not directly attributed to the Case and Kelsall report, is a conclusion reached in Section 8.4 regarding the creation of preferential pathways. On page 8.4.3-61 of the SCP, the scenario where an undetected fault exists is considered. One of the major potential impacts described is that site characterization penetrations would function as localized preferential pathways for gaseous or liquid-phase releases from the repository horizon. However, in the discussion of the nominal scenario class (page 8.4.3-56), the permanent effects of exploratory shaft construction are concluded to not create preferential pathways. The Fernandez et al (1988) reference is provided in which the Case and Kelsall study is used to develop the conceptual model of the MPZ. My concern is that the Fernandez analyses do not consider the case where the exploratory shaft intersects a recognized fault leading to the repository area. It is unclear what procedure will be used to mitigate the situation (e.g. sealing the fault) but the scenario appears to be similar enough to the undetected fault scenario that a preferential pathway results.

Conclusions:

Based on my review, the data used are considered reasonable and representative for the Yucca Mountain site. The constitutive relationships and analytical methods are also judged to be appropriate given the current understanding of the site. Simplifying assumptions are identified and their implications discussed. The apparent discrepancy identified in 8.4 concerning the degree of conservatism in the analytical methods developed by Case and Kelsall does not impact the overall conclusions reached in section 8.4.3.2 concerning the effect of the shaft on repository performance.

In a related manner, it appears that the discussion in Section 8.4.3 of the SCP concerning preferential pathways is inconsistent in its treatment of faults intersecting the exploratory shaft. The case where a fault is intersected and identified as such is not considered.

Recommendations:

The nominal scenario (present site conditions) where, during construction, one of the exploratory shafts intersects and identifies a fault extending to the repository area should be evaluated and the results provided in subsequent SCP Progress Reports. In addition, the appropriateness of including a discussion on the feasibility of sealing such a fault and the criteria for doing so should also be considered.

Reference:

Fernandez, J., T. Hinkebein, and J. Case, 1988. "Analyses to Evaluate the Effect of the Exploratory Shaft on Repository Performance of Yucca Mountain," SAND85-0598, Sandia National Laboratories, Albuquerque, NM.

23-Jan-1989

Joe R Tillerson

Joe R. Tillerson

Review of: Costin, L. S., and S. J. Bauer, 1988. Preliminary Analyses of the Excavation Investigation Experiments Proposed for the Exploratory Shaft at Yucca Mountain, Nevada Test Site, SAND87-1575, Sandia National Laboratories, Albuquerque, NM. (SAIC Ref. No. 3040)

Data Reasonableness

1. Data are not in exact agreement with the RIB (version 3.0) but are sufficiently close to be judged reasonable values to be used in simulations of experiments proposed for the ESF at Yucca Mountain.

The authors do a very good job of identifying the data used in the evaluations. They give a table for each of the three analyses that identify the data used and the related RIB values (see Appendices A, B, and C). The three excavation experiments analyzed are : Shaft Convergence, Demonstration Breakout Rooms, and Sequential Drift Mining.

2. Because of the need for simulation of the excavation effects on the liner and the simulation of the effects of the repository and seismically induced loads, it is recommended that properties for the concrete used (proposed) in liner construction be considered for inclusion in the version of the RIB used for ESF Title II design.

3. Because of the need to estimate the stresses in the liner at several depths, it is recommended that in situ stresses as a function of depth be considered for inclusion in the version of the RIB used for ESF Title II design.

Reasonableness of Analysis Methods

1. The elastic and elastic-plastic methods used in this report are, in my opinion, reasonable and appropriate for simulating the mechanical response of openings in the Topopah Spring tuff.

The authors appropriately identified the codes and analysis approaches (boundary conditions, initial conditions, geometry, types of elements, etc) used and gave explicit recognition of limitations of them. Many limitations were related to the preliminary nature of the calculations, the degree of definition of the experiments, and the simplifying assumptions necessary to complete the calculations.

Treatment of Uncertainty

1. Uncertainty is, in my opinion, treated appropriately for the three experiments in several ways.

In all cases the need for more analyses is recognized as more is known about the specifics of the experiment and, ultimately, as the actual conditions that exist underground are known (i.e. site specific material data are collected). Simplifying assumptions were identified and some potential effects of those assumptions were discussed. The authors examined the influence of blast damage zone on shaft convergence and potential stresses in the liner. Hourglassing or keystoning effects in the finite element meshes were evaluated. They recognized that "Interpretation of the calculated results should consider three factors that may cause measured convergence to differ from the estimates presented here." (The factors are delay time between excavation and instrumentation, effects of the opening and face of the DBR, and joints and fractures in the rock. See Page 40). Uncertainties regarding simplifying assumptions, such as 2-D crossections to simulate potential 3-D effects, were also discussed.

Appropriateness of Analysis use in ESF Title I Design Evaluations

1. The analyses have, in my opinion, been appropriately used in SCP section 8.4 in the evaluations of ESF Title I design completed to date.

The analyses were appropriately used as one of several that provide an indication of the stress altered region near underground drifts and alcoves and hence, help form the basis for the definition of the needed standoff between drifts. In addition, the analysis results support the conclusion that there would be no mechanical interference expected between the shafts (14 feet diameter openings separated by 300 feet). Finally, the analyses are appropriately used as the basis for the evaluation of shaft convergence, demonstration breakout room, and sequential drift mining experiments planned for the ESF.

Recommendations: None related to the ESF Title I design but three recommendations are offered for inclusion of properties in the Reference Information Base for use in the Title II design that are related to stress analyses of the liner and underground openings. Specifically, the RIB should contain:

1. Concrete properties for the materials planned for use in the liner.

2. In situ stress as a function of depth (or stress ratios) to allow evaluation of the stresses in the liner at various elevations including (for contingency planning) the Calico Hills.

3. Properties of the materials planned for use in support systems proposed for the ESF including those systems that may be considered if stability problems are encountered in anomalous zones (for example, shotcrete properties).

The properties should be available in the RIB or other appropriate project document prior to the initiation of analyses for Title II design that use the properties as input.

11-Jan-1989

Joe R. Tillerson

Joe R. Tillerson

Review of: Costin, L. S., and E. P. Chen, 1988. An Analysis of the G-Tunnel Heated Block Thermomechanical Response Using a Compliant-Joint Rock-Mass Model, SAND87-2699, Sandia National Laboratories, Albuquerque, NM. (SAIC Ref. No. 3844)

Data Reasonableness

1. The material properties used in the analyses are specific to the welded tuff formation found in G-Tunnel; however, since they do not generally differ unacceptably from those of the proposed repository horizon as evidenced by the ranges of values found in the RIB (version 3.0), it is reasonable to use the results of these analyses as a guide to the anticipated performance of a similar heated-block test proposed for the ESF.

The data used in the report are taken from 5 references related to the heated-block test performed in G-tunnel. While these data appear reasonable, it should also be noted that many of the material properties, especially the joint properties, are varied in the analyses described in the report. While the data for the thermal expansion properties for G-tunnel are generally lower than the RIB values, the analysis results would still be reasonable for use at Yucca Mountain because the experiment is designed to be stress-controlled, i.e. free expansion is designed to be allowed around the block and stresses are imposed on the block via flatjacks. Also, since the extent of stress change is expected to be small in regions near the edge of the thermal pulse, the use of the temperature rise as the controlling criteria in establishing the zone of influence for this test is reasonable.

Reasonableness of the Analysis Method

1. The results of the analyses in this report confirm, in my opinion, the reasonableness and appropriateness of the use of the compliant joint model and the conduction heat transfer models in the simulation of the response of tuff to thermal and mechanical loading.

The above statement is not meant to imply that the compliant joint model has been shown to be adequate for all types of loading. In this report, the model is shown to have some shortcomings, particularly related to unloading response and to thermally induced loadings. These analyses do, however, represent state-of-the-art application of a complex model to complex mechanical and thermal cycles. Furthermore, one of the purposes of the testing planned for the ESF is to aid in evaluating codes such as are used in these analyses. The codes (JAC, QMESH, COYOTE, and MERLIN) and their roles in the analyses are identified clearly in section 3.0 of the report. Readers are appropriately referred to numerous supporting references for details of the calculations.

11-Jan-1989

Treatment of Uncertainty

1. The authors have, in my opinion, devoted significant and substantial attention to uncertainties related to the application of the numerical models to the simulation of the heated-block experiment.

The recognition of the treatment of uncertainties started in the abstract of the report as the authors noted that "key model parameters were varied in order to assess the sensitivity of the solution to variation of these parameters." Limitations of the usability of the model relative to the characteristic spacing of the joints were recognized. Joint parameters (half-closure stress, friction coefficient, shear compliance, and unstressed aperture) were varied in an attempt to document the sensitivity of the results to parameter variations. The accurate prediction of the loading compliance of the rock mass was noted along with the straightforward presentation of the lack of predictive capability for predicting the permanent normal deformation of the joints. The capability for relatively accurately simulating the thermal response of the block (considering radiation effects) was demonstrated; although the basic behavior of the block was captured in the thermomechanical calculations, the qualitative agreement between calculated and measured data were less satisfactory. In initial simulations of the response of the block to uniaxial loading, calculated strains were substantially higher than measured values; this led to modification of the lateral pressure boundary conditions, improved correlation between calculated and measured values, and proposed recommendations for changes in the experiment procedure when the test is conducted in the ESF. Effects of nonuniform joint spacings were shown to be small.

Appropriateness of Analysis use in ESF Title I Design Evaluations

1. This is a detailed analysis of a prototype heated-block test conducted in G-tunnel; the analyses have been appropriately used in SCP section 8.4 in evaluations of the ESF Title I design.

The analyses are appropriately used to support the estimate of the thermal zone of influence of this test (about 6 m beyond the test alcove), the extent of the 100 C isotherm, and the statement that the analyses indicate that the rock beyond 8 m from the edge of the block is not significantly distrubed.

Recommendations: None relative to the ESF design but the suggestions for improving the heated block test should be considered in the design of the experiment planned for the ESF.

Cl Noronha 1-27-89

TECHNICAL ASSESSMENT REVIEW SAND85-0002
PART I - ELEMENT 4

Reviewer: Clifford J. Noronha Date: 27 January 1989

Document Reviewed: Dudley, A.L., R.R. Peters, J.H. Gauthier, M.L. Wilson, M.S. Tierney, E.A. Klavetter, December 1988, "Total System Performance Assessment Code (TOSPAC) Volume 1: Physical and Mathematical Bases", SAND85-0002, NNWSI, Sandia National Laboratories, Albuquerque, NM. (SAIC Reference Number: 3818)

Reasonableness of the Analyses

This report describes the mathematical formulation of the TOSPAC code. In general, the code addresses all the processes relevant to 1-dimensional unsaturated flow and transport and treats them with the necessary degree of complexity.

The general governing equation described in this report is one for unsteady state, variably-saturated flow in a dual-porosity medium (Equation 2.1-5). This equation has various terms describing the storage capacitance due to compressibility of water and dilation of rock (zero, if medium is rigid).

This review focuses on the example hydrological problems described in Section 2.3 as these are the only actual analyses referred to in Section 8.4 of the SCP as being relevant to the ESF Title 1 design.
The conceptual model (Figure 2.3-1) is a simple, vertical one-dimensional column of five hydrogeologic units from the water table (0.0 m) up through the repository horizon, TSw (~240 m) to the land surface (530 m). In the abbreviated, unit-naming convention in Figure 2.3-1, the subscript "w" is for welded and signifies low conductivities. The subscript "n" is for non-welded and signifies high conductivities, unless it is followed by "z" for zeolitized in which case the conductivity is low.

Section 2.3.1 defines steady-state problems which illustrate the use of the STEADY routine in the code. This section was published earlier in SAND85-0854C by Peters et al., 1986 which was also reviewed as part of this exercise. Nevertheless, the conclusions will be repeated here for the sake of stand-aloneness. Three different percolation rates (0.1, 0.5, and 4.0 mm/yr) are applied to the column for each of the two possible sets of properties for the non-welded Calico Hills unit (CHn): v - vitric and z - zeolitized. This is a total of six distinct cases.
The travel times in each hydrologic unit are presented in Figures 2.3-8 through 2.3-10 in the form of three bars; one for the matrix, one for the fractures, and a "minimum" for the most conservative combination of the two. From these results, the travel times from the proposed repository location to the water table for each of the six cases are deduced and summarized in Table 2.3-2. Five of the six cases yield a travel time of approximately 10,000 yr to 400,000 years which more than adequately satisfies the current 10CFR60 travel time regulation of 1000 years. The sixth case, involves the highest percolation rate of 4.0 mm/yr, which forces more flow through the fractures rather than the low conductivity,

Horonka 1-27-89

zeolitized Calico Hills (CHnz). This predominance of fracture flow reduces the travel time to 3 years. However, the regulations specify the travel time to the "accessible environment" which could involve a prolonged residence time within the saturated zone following the 3 years in the unsaturated zone.

Section 2.3.2 demonstrates the transient capability of the code by exercising the DYNAMICS routine. The six cases described in Section 2.3.1 are used as the initial condition and the flux rate in each case is instantaneously doubled in the form of a step function. These transient cases are shown in Table 2.3-3. The time required for each case to reach the new steady state is determined. This is designated as the pulse travel time. In each case, STEADY is used at the higher flux rates to come up with the corresponding actual water travel time for the entire column. These two performance measures are tabulated in Table 2.3-4. The basic conclusion made from this table is that as the flux rate increases, the saturation increases and both times decrease. However, in the flux transition from 4 to 8 mm/yr for example, although the actual tracer travel time is 1700 yr for CHnz, the pulse travels from one steady-state to the other in as little as 2 years. Especially at higher saturations, such flux-change pulses propogate rapidly due to the absence of significant additional water-storage capacity.

I believe that the analyses carried out are appropriate and the approach used is reasonable.

Reasonableness of Data

The Reference Information Base (Version 3.0) contains no hydrologic data. Most of the raw data used in this report is summarized and compiled in Table 2.1-2. The table is divided into matrix and fracture properties. Within each section, various parameter values are given for the five different stratigraphic units being considered in this report. PPw is not used.

I found that most of these values had been reproduced in Table 3-26 of the SCP. However, the Kmb value for CHnz of 2E-11 m/s (1.73E-6 m/d) was a little below the range given in Table 3-27 of the SCP. Another source of these data was found to be Table 6-18 of the Yucca Mountain EA. Porosity values compared reasonably well between various references. Because of its significance to even steady-state flow calculations, I focused my attention on the hydraulic conductivity values, Kmb. While TSw and CHnz were within the same order of magnitude between the EA and the subject report, the CHnv value of 2.7E-7 m/s in Table 1 was almost two orders of magnitude higher than the 107 mm/yr (3.4E-9 m/s) reported in the EA.

Notes to Table 1

(b) Kmb = Km (1-nf) = Km (nf <<< 1)
(g) Kfb = Kfnf

All other data values in Table 1 look reasonable.

Treatment of Uncertainty

The authors have addressed uncertainty adequately in their choice of the wide range of parameters. The two compositions of the unit CHn considered, correspond to the extremes that may be found at Yucca Mountain; either it is vitric with a relatively high conductivity (CHnv) or it is zeolitized with a relatively low conductivity (CHnz). In addition, the percolation rates in Tables 2.3-1 and 2.3-3 span the range suggested for Yucca Mountain (DOE, 1984). This range also encompasses all flow regimes from predominantly matrix to predominantly fracture.

Appropriate Use in SCP Section 8.4

These example problems are summarized in Section 8.4.3.2.1.2, Item 6 of the SCP. For the steady state cases, the SCP correctly concludes that at 0.1 mm/yr the flow is predominantly in the matrix, at 4 mm/yr predominantly in the fractures, and at 0.5 mm/yr the flow is in both regimes. For the transient simulations, the SCP mentions the fact that while the transition from 0.1 to 0.2 mm/yr takes 200,000 years, the transition from 4 to 8 mm/yr takes only (2 to 150) years.

As pointed out earlier, the matrix property data from Table 2.1-2 in this report is reproduced in Table 3-26 of the SCP. During this review, our primary focus was Section 8.4, but if appropriate information was not found in this section, we looked for it throughout the SCP. Therefore, although this data is compiled in Section 3, the conclusions drawn in (Section 8 of) the SCP, are based on the use of these specific data values. Different data would undoubtedly result in different conclusions.

The discussions in SCP Section 8.4 are an accurate summary of the significant conclusions drawn in the subject report.

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Charles F. Voss 1/23/89

Reviewer: Charles F. Voss Date: January 20, 1989

Document Reviewed: Ehgartner, B.L., 1987. Sensitivity Analyses of Underground Drift Temperature, Stresses, and Safety Factors to Variation in the Rock Mass Properties of Tuff for a Nuclear Waste Repository Located at Yucca Mountain, Nevada," SAND86-1250, Sandia National Laboratories, Albuquerque, NM.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (Version 3.0)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 3.0 Reference Information Base

Version 3.0 of the RIB was reviewed as part of the TAR and an assessment was made of the reasonableness of the data. The review was performed by several TAR members based on their technical area of expertise and familiarity with properties of the Yucca Mountain site. Comments concerning the reasonableness of the RIB values are contained in the review of the RIB included in Appendix I.

2. Appropriateness of the data and parameters used in the analyses

The stated objective of the report was to provide insight into the relative importance of the thermal and thermal/mechanical properties that impact the stability of emplacement drifts. Expected ranges of parameters were used in the two-dimensional thermal and thermal/mechanical models. The average rock mass property values for TSw2 in the RIB (1986 version) were used in the analyses. The range of parameter values considered are based on the combined data from TSw1 and TSw2. This results in larger ranges of values than the TSw2 data alone. Based on a comparison of the values used with Version 3.0 of the RIB and for use in sensitivity analyses, I consider the data used in this report to be reasonable.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

The rock mass surrounding a horse-shoe-shaped emplacement drift was modeled as a linear elastic medium with decaying linear heat sources representing the waste canisters. A Coulomb failure criteria was used to estimate the onset of failure in the rock mass. I consider these assumptions appropriate for modeling the behavior of the tuff rock at the proposed repository level based on my knowledge of the laboratory and field experiments that have been performed by the Yucca Mountain Project participants and the stated objectives of the analyses.

4. Consideration of data uncertainty

The natural variability of the thermal/mechanical properties was considered by using conservative ranges of values for the parameters (see item 2 above) obtained from the RIB available at the time the analyses were performed. The analyses quantify the effect individual variations of the model input properties have on the temperature, stresses, and stability of the rock around the drift. The parameters determined to have the greatest impact on design are then varied simultaneously over the expected ranges using the probabilistic point estimate method. The analyses provide an estimate of the probability of rock failure around the opening at various times. The author recognized the analyses do not consider the uncertainty associated with the conceptual models for drift stability (i.e., the failure criteria used) or field conditions among others.

5. Use of the analyses to form conclusions in 8.4

Section 8.4.3.2.3.1 appears to mistake the results of the analyses. On page 8.4.3-29 the following statement is made: "The results indicate that changes in rock strength and modulus in the Topopah Spring had a greater effect on factors of safety than did the other parameters, but in no case was failure of the rock mass predicted. The probability of encountering poor ground conditions that may need supplemental ground support for the horizontal emplacement drift was estimated to be approximately 20 percent." However, on page 31 Ehgartner reports "Approximately 20 percent of the possible values for the thermal and thermal/mechanical properties result in rock mass safety factors less than 1....Factors of safety less than 1 imply localized failure of the rock mass." The Ehgartner 1987 reference is not used again in Section 8.4 and it unclear whether the misinterpretation noted above was directly used to support any of the conclusions reached in section 8.4.3.3 concerning the performance objectives (e.g., the adequacy of a 30 m separation between the ESF and potential waste panels).

Recommendations: Based on the observed discrepancy noted in item 5, it is recommended that the author(s) of Section 8.4.3.3 be requested to document the extent that the Ergartner 1987 reference was used to reach conclusions concerning the potential impacts of site characterization activities on the performance objectives for the site. An assessment should be made by the author(s) whether the conclusions reached in 8.4.3.3 are changed in any way as a result of this information.

TECHNICAL ASSESSMENT REVIEW
Reviewer: Paul L. Cloke
Field: Geochemistry

PART I - ELEMENT 4

Reference: Fernandez, J. A., Hinkebein, T. E., and Case, J. B., 1988. "Selected Analyses to Evaluate the Effect of the Exploratory Shafts on Repository Performance at Yucca Mountain", SAND85-0598, Sandia National Laboratories, Albuquerque, NM.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objective of this review is to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The overall evaluation process considers the following:

1. the reasonableness of the data in the RIB (Version 03.001)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

This portion of the overall review of this reference considers only items 1 through 4, above, and is restricted to geochemical data and concerns. To a large extent the geochemistry has been rolled up into hydrology in the ESF Title I design, and, therefore, hydrogeochemical concerns are also included. Most of this report is hydrological; only sections 6.2, 7.1, and 8.2 were reviewed by me.

1. Reasonableness of the parameter values in Version 03.001 Reference Information Base

This version of the RIB contains no geochemical data, and only one set of data, on annual precipitation, relevant to the hydrogeochemical concerns addressed in this review. The average annual precipitation at Yucca Flat was used by the reviewer together with an estimated area of the Yucca Mountain site, obtained by approximate measurement of the area of the outline shown in SCP/CD, Overview, Figure 3-2, to calculate a reasonable expected gallonage of precipitation expected on the site. This calculation yielded about 390 million gallons/yr., in reasonable agreement with the value of 230 million gal/yr. cited in SCP section 8.4.3.2.1.3, in view of the differences in elevation and geographic position.

2. Appropriateness of the data and parameters used in the analyses

The geochemically related data used in SCP Section 8.4 include only the following: 1) effects of grouts and concrete on ground water chemistry, 2) sealing and backfilling of shafts, and 3) gaseous releases.

The effects of grouts and concretes were analyzed through experiments, by hand calculations, and by computer calculations using WATEQ. These are all appropriate ways of assessing the changes in the liquid and solid geochemistry. The results are generally reasonable and in concordance with this reviewers expectations. It should be noted, however, that the hand calculation reported on page 117 of a pH of 13.88 resulting from an alkali concentration of 0.75 M is clearly wrong. The "concentration of alkali" is cited from Barnes, 1983 (Structure and Performance of Cements, Applied Science Publishers, London), a copy of which could not readily be found in Las Vegas. At this high an ionic strength activity coefficients must be estimated by a method that is suitable for such conditions. It is likely that the proper activity coefficient is in the range 0.01 to 0.1, so the actual pH would lie in the range 12 to 13, not close to 14. [It should also be borne in mind that WATEQ is not suitable for use at high ionic strengths.] It is also not clear, in view of the text earlier in this paragraph, that a distinction is made between the concentrations of alkali metal ions and hydroxide ion. Only the hydroxide ion activity has a direct relation to pH; the concentrations and activities of Na^+ and K^+ have no necessary relation to pH. In view of the probable presence of other anions in addition to hydroxide it seems likely that the pH will be lower than indicated by the simple correction noted above. However, in a qualitative sense, which is actually all that is utilized in the SCP, it is still correct that the pH of water in contact with cement for a few days should be high, and it is reasonable that with time it will drop to somewhat lower values as silica and perhaps other substances that can lower the pH react with the hydroxide. In this connection it is worth noting that the concentration of silica in J-13 water reported in Table 7-1 of the report approximately doubles as a consequence of reaction with concrete, even though the authors do not identify this as a significant increase. Activity coefficients appear consistently not to be used in the hand calculations.

This same problem, assuming that Fernandez, et al, used Na^+ and K^+ to estimate OH^-, recurs on page 119 in conjunction with diffusion. I.e. it may be that the concentration of hydroxide is overestimated. In this case the calculations will be overconservative. If this is a problem, it occurs again in Figure 6-1.

As indicated in section 6.2.2 the chemical equilibrium model is intended only to estimate the nature and quantity of precipitates. Whereas the quantities may be somewhat in error, as a consequence of the potential problems noted above—especially the inability of WATEQ to handle high ionic strengths, the nature and trends of the results are all reasonable and are compatible with similar calculations done by others and with observations in evaporative lake sediments where pH changes of a similar magnitude occur. This last is relevant because of the prediction of precipitation of some of the magnesium silicate minerals and their observation in the sediments.

Modeling of the effects of precipitation on porosity and permeability is very difficult and uncertain; Berner's model is not the only in existence. This problem has been studied extensively by the petroleum industry with no definitive consensus on how to do it. Fortunately, this is not an important aspect of this paper in terms of its application to the design or performance of the ESF.

No difficulties or concerns were identified with respect to the treatment of sorption capacity, as described in section 7.1. All values used appear reasonable and appropriate.

No geochemical difficulties were identified with respect to the treatment in section 8.2, Remedial Measures to Restore the Modified Permeability Zone. However, the effect of this remediation, which involves the injection of grout into the wall rock of the shaft after removing the liner, on the long-term capability of the site to isolate waste was not addressed, either here, in the report by West (1988) which cites the present reference, or in the SCP Section 8.4. This is not viewed as a serious problem inasmuch as the effect should be nearly the same as that of emplacing the shaft liner and leaving it in place, which was addressed. Part of this remedial process is to emplace backfill and seals.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used.

Except as noted above the conceptual models and analyses are all adjudged to be appropriate.

4. Consideration of data uncertainty.

Some qualitative consideration was given to uncertainties in citing data from analyses of J-13 water and experimental results. However, no formal uncertainty or sensitivity analysis was done. The uncertainty of the data base for WATEQ was not addressed.

5. Use of the analyses to form conclusions in 8.4

The analyses are used to support in respect to the localization of effects of grouts and concretes, to changes in groundwater conditions very close to these materials, and, for the backfill and seals, to close off potential pathways for liquids and gases to the accessible environment. These conclusions are supported by the data presented. The analyses do not indicate that the the long-term waste isolation capability of the side will be compromised, nor that the ability to characterize the site will be compromised, nor that ESF site characterization activities will not be able to provide representative data.

Conclusions: Based on my review of the document referenced, I consider the data used and the analytical methods used generally appropriate and consistent with the objectives of the report, with respect to geochemistry. It is appropriate to use this report to support Section 8.4 in respect to the conclusions noted above. The results are judged to be sufficiently conservative, and in some cases perhaps overly conservative.

Recommendations: None.

Paul F. Clark   Jan 11, 1989

United States Department of the Interior

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DENVER, COLORADO 80225

IN REPLY REFER TO:

WBS#: 1.2.5.2.1
QA : "QA"
January 13, 1989

August Matthusen
Science Applications International Corp
Suite 407 101 Convention Center Drive
Las Vegas, NV 89109

Dear Augie:

Enclosed are four letters that were prepared as a result of reviews that were conducted as part of the Technical Assessment Review (TAR). The reviews, which were made for the TAR subcommittee on "Comparative Evaluation of Alternative ESF Locations", were used to evaluate whether appropriate conclusions are made in Section 8.4.3 of the SCP regarding the effects of the exploratory shafts on the waste-isolation capability of the Yucca Mountain site. The letters provide results of reviews that were made on parts of Section 8.4.3 of the SCP, Fernandez et al. (1988), and West (1988). I am transmitting copies to you because they may have a bearing on the findings of your subcommittee on "data reasonableness".

In general, the reviewers conclude that: 1) the models, assumptions, boundary conditions, and data inputs that were used in the analysis were reasonable and appropriate; 2) data uncertainties were considered and conservative approaches were taken; 3) the conclusions that were drawn were reasonable and appropriate; and 4) the conclusions were utilized appropriately in the judgments made of the potential impacts of the ES on performance.

The reviewers raised certain technical points that, if proven to be valid, could impact design. In addition, in some cases, additional or alternative technical approaches or models were suggested. Generally, the technical concerns raised are expected to be compensated for by the conservative measures that will be taken in design. These concerns do not reflect adversely on the Title I design approach but should be considered in Title II.

Sincerely yours,

William E. Wilson

William E. Wilson
USGS/Yucca Mountain Project

Enclosures
WEW/pnb
TAR.WEW

Science Applications International Corporation
An Employee-Owned Company

WBS: 1.2.3.3.6.2
QA: "N/A"

December 21, 1988

W.E. Wilson III
Yucca Mountain Project Branch
U.S. Geological Survey
P.O. Box 25046, MS-421
Denver Federal Center
Lakewood, Co 80225

Subject: Assessment of 8.4 Conclusions About Impact of ES on Waste Isolation

Dear Bill:

Josh Marvil and I have reviewed Sections 3.0, 6.0, 7.0, and 8.0 of Fernandez et al (1988). We found that the same conclusions that are drawn in SCP Section 8.4 regarding the impact of the ESF on waste isolation were also clearly and directly presented in the Fernandez paper. In general, we also found that: (1) the conceptual and numerical models used were appropriate; (2) the assumptions were conservative; (3) the boundary conditions and data inputs were reasonable, when presented; and (4) the conclusions that were drawn were reasonable and appropriate. One concern that we had was that some of the data used in the models were not included in the report, but instead were referenced. We have not checked the references, but would need to in order to determine the data's reasonableness. In the following paragraphs, our specific comments/concerns for each of the sections are addressed.

Section 3.0 Potential for enhancing radionuclide release resulting from selected water flow scenarios

1. Fernandez et al (1988) used a model involving laminar flow between parallel plates governed by the cubic law of fracture flow (pg 52). In this model, the Green-Ampt equation was used to account for matrix imbibition, and the Van Genuchten parameters from Klavetter and Peters (1986) were used to evaluate matrix pressure. The use of the Green-Ampt equation is questionable because there are more rigorous analytical and numerical methods that could have been selected (e.g. Brooks Corey, Modified Richards, Van Genuchten, Philip). The use of the cubic law equation with laminar flow is also questionable as the cubic law probably has little validity in rough-surface fractures. Also, the Van Genuchten parameters from Klavetter and Peters (1986) are in conflict with those of other researchers (Flint, unpub; Weeks; unpub).

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2. Fernandez et al (1988) did not consider the presence of perched water in any of the ES water accumulation scenarios. Perched water must be considered before construction of the ES as it poses potentially deleterious and unpredictable problems.

Section 6.0 - Potential for changing the conductivity of the shaft liner, the modified permeability zone, the shaft fill, and the shaft sump

1. Fernandez et al. (1988) assume local equilibrium for their modeling efforts. Even though this is a conservative assumption, why not consider diffusion of ionic species and chemical kinetic rate processes (we have the technology) and model the entire system more realistically?

2. In calculating diffusion through the concrete liner using Fick's Law, an empirical diffusion coefficient (€) of 0.28 (p. 119) seems low. It would be interesting to know where this value came from. Similarly, the value for Eh (-256 mV, p. 122) seems low and should not be arrived at simply "to keep minerals in solution". An expected value of Eh at pH-6.9 is 816 mV (Garrels and Christ, 1965). It is recognized that Eh is difficult to measure in natural systems out of equilibrium with air because of the problem of introducing electrodes without simultaneously introducing air. The authors' have chosen a conservative value of Eh, but should explain their choice in more detail.

3. Throughout Chapter 6.0, Fernandez et al. (1988) take conservative approaches to simulate the worst-case scenarios. For the present analysis of the concrete liner, they only estimate the nature and quantity of precipitates from the interaction of ground water with the concrete liner. An analysis of the interaction of ground water, the concrete liner, and <u>tuff</u> at ambient conditions and as a function of temperature is even more important.

Section 7.0 - Potential for impacting repository performance resulting from penetration of the Calico Hills unit by the ES

The conceptual model used in this section seemed appropriate. The authors do not reach any quantitative conclusions, but merely reason that the impact of water percolating through the shaft fill and MPZ on the sorption potential of Calico Hills is negligible. It would be more appropriate to express the distribution coefficient (Kd) on a per-unit-surface area basis for fluid migration through fractured materials instead of using mass density in the definition, as the majority of flow would be through fractures.

Section 8.0 - Possible remedial measures to modify physical features associated with the exploratory shaft facility

In this section, the liner removal and MPZ restoration methods considered were appropriate, and the conclusions reached were reasonable. Due to the fact that numerical models with the associated data inputs, boundary conditions, and assumptions were not required to evaluate the remedial measures, there was little to review in this section.

Sincerely,

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

S. G. Doty/J. D. Marvil

SGD:JDM/cp

cc: R. L. Wise, SAIC-Golden
T. G. Barbour, SAIC-Golden
Project File: 527-32-1-1
YMP LRC

United States Department of the Interior

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TAKE PRIDE IN AMERICA

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January 13, 1989

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The reviewers raised certain technical points that, if proven to be valid, could impact design. In addition, in some cases, additional or alternative technical approaches or models were suggested. Generally, the technical concerns raised are expected to be compensated for by the conservative measures that will be taken in design. These concerns do not reflect adversely on the Title I design approach but should be considered in Title II.

Sincerely yours,

William E. Wilson

William E. Wilson
USGS/Yucca Mountain Project

Enclosures
WEW/pnb
TAR.WEW

WBS: 1.2.3.3.6.2
QA: "N/A"

December 22, 1988

To: Bill Wilson, Technical Advisor

From: Rob Trautz, reviewer, Gaseous Phase Flow Project Chief RT

Subject: Review of Selected Analyses to Evaluate the Effect of the Exploratory Shafts on Repository Performance at Yucca Mountain, sections 4.0 and 5.0, by Fernandez and others (1988).

Fernandez and others (1988) determine the potential impact air movement through backfilled drifts, shafts, ramps or the disturbed zone surrounding these structures may have on gaseous phase radionuclide releases. Section 4.0 of their report deals with possible releases caused by air movement resulting from convective forces while section 5.0 looks at air movement resulting from barometric pumping. The authors determine the pneumatic conductivity of the shaft backfill material required in order for the effects of convection and barometric pumping to be minimized. I reviewed the aforementioned sections and summarize the findings by section as follows.

Section 4.0

1. Page 79, paragraph 1: A performance goal was established by the authors stating that air flowing through the shafts and their disturbed zones should not exceed 25% of the total flow of air from the repository. This seems to be an odd means of establishing a performance goal for gaseous radionuclide release rates. What concentration of C-14 and I-129 gases are present in the flowing air? Are the concentrations very high, below safety standards or non-detectable? If the contaminant concentrations are very high then one could be allowing a significant amount of gaseous radionuclides to reach the accessible environment based on the 25% total flow criteria.

2. I found that the authors utilized an appropriate model given by Hartman (1982, p.244, Equation [9-3]), but made the problem more difficult than it needed to be and less accurate by accepting the assumption that the gas is incompressible and dry (Appendix E, p.234 of authors' report). It is true that a 5% change in gas volume will result due to a change in pressure of 0.72 psi at atmospheric conditions (14.7 psia) as stated by the authors and Hartman (1982), but in the case of the repository the gas will undergo a 38% contraction as it rises up through the shaft. This can be demonstrated by utilizing the ideal gas law;

one mole of gas will occupy 31.8 liters at 115 C and 1 atmosphere, and only 23.4 liters at 13 C and the same pressure. This corresponds to volumes occupied by the gas at the ES bottom and top, respectively. Thus the utilization of equation (E-2), the equation of state for an incompressible fluid with constant volumetric thermal expansion (i.e. constant beta) in the authors' analysis, is inappropriate in this case. In addition, the authors have mixed two equations of state for the same fluid, that is, Hartman's Equation 9-3 (the authors' Equation [E-1]) was derived from the ideal gas equation which takes into account gas compressibility, and the authors' Equation (E-2) which is for an incompressible fluid with constant thermal expansion coefficient.

The mixing of equations of state in mid-analysis is not rigorous and has resulted in a poor estimate of the draft pressure calculated by the authors. The reviewer used Equation (9-5, p.244) in Hartman (1982) to calculate the natural ventilation head as follows:

$T_1 = 13^\circ C = 55.4^\circ F = 515.1\ ^\circ R$
$T_2 = 23^\circ C = 73.4^\circ F = 533.1\ ^\circ R$
$T_3 = 115^\circ C = 239^\circ F = 698.7\ ^\circ R$
$T_4 = 13^\circ C = 55.4^\circ F = 515.1\ ^\circ R$
$L = 314$ m $= 1030$ ft
$t_d = 73.4 - 55.4 = 18^\circ F$
$t_u = 239 - 55.4 = 183.6^\circ F$
$R = 53.35$ ft-lb/lbm-$^\circ R$

$$H_n = (2116.2/5.2)\left[(533.1/515.1)^{1030/(53.35)(18)} - (698.7/515.1)^{1030/(53.35)(183.6)}\right]$$

$$= 1.73 \text{ inches } H_2O \text{ (0.502 kPa)}$$

This estimate of draft ventalation head is easily determined from the surface pressure (p_1, assumed to be 87,111 Pa by the reviewer), and temperatures at the top and bottom of the upcast and downcast shafts (T_1 - T_4, provided by the authors). In addition, Hartman's Equation (9-5) does not require that the gas behave as an incompressible fluid. The authors incompressibility assumption has resulted in a 20% (1.4/1.73/) underestimation of the draft ventalation head.

Neglecting the effect of water vapor on the draft head or pressure is also a poor assumption leading to a nonconservative estimate of air flow. The density of mine air saturated with water vapor is actually less than dry air (at the same temperature and pressure) thus requiring less energy to lift the same volume of gas. In addition, it is doubtful that the air would be perfectly dry even at elevated repository temperatures of 115 C. Near-field canister temperatures might be extremely high, but far-field cooler temperatures would help to moderate temperatures at the exploratory shaft. Under moderate conditions (60 C), mine or pore gas in equilibrium with free water in the pore space held by a tension of 100 bars would still have a relative humidity greater than 90%, and 50% for a 1000 bar tension. Thus the conservative approach would be to assume that the gas is 100% saturated at the repository temperature or at 100°C if virtual temperatures are employed.

Equation (9-5) in Hartman (1982) can also be used to determine the draft head when water vapor is present by substituting the virtual temperature for the absolute dry-bulb temperatures. Virtual temperature is the temperature which dry air must have at the given barometric pressure in order to have the same density as moist air at the same pressure, given temperature, and mixing ratio (List, 1968). The mixing ratio is simply the mass of water vapor to mass of dry air in the gas mixture. Virtual temperatures were calculated by the reviewer using Equations (18) and (19) on page 297, and Tables 72 and 73 in List (1968). Saturated mixing ratios (r_w) cannot be determined for temperatures above 100 C, so this temperature was used to reflect repository conditions. A saturated mixing ratio at 100 C was calculated from the mass of vapor and mass of dry air in the mixture at this temperature (American Gas Association, 1966, p.1/25, Table 1-27). Virtual temperatures, relative humidities and pressures used to calculate the draft head are summarized below.

p_1 = 87111 Pa = 1819 PSF
T_{v1} = 13.19 C @ 87.111 kPa and 10% relative humidity
T_{v2} = 79.99 C @ 87.111 kPa and 100% relative humidity
T_{v3} = 325.8 C @ 101.595 kPa and 100% relative humidity
T_{v4} = T_{v1}

Converting these values to the appropriate engineering units for use in Equation (9-5) of Hartman (1982) and performing the computations results in a draft head of 4.1 inches of water (1021 Pa). This value is nearly three times higher than that estimated by the authors and thus the authors' assumption that a dry gas analysis leads to a conservative approach is incorrect. It should be noted that even the reviewers analysis using virtual temperatures may be oversimplistic due to the fact that condensation will take place as the moist saturated air rises in the shaft and cools making the analysis more complicated.

The reviewer does not have access to the resistance model utilized by the authors to determine the pneumatic conductivity of the backfill material required to minimize airflow. Thus it is not possible for the reviewer to determine the pneumatic conductivity of the backfill based on his recalculated draft heads. One thing is certain, an increase in draft head over that reported by the authors will require a decrease in the pneumatic conductivity in order to maintain the same flow rate.

Section 4.0 Summary

In conclusion, the reviewer feels the authors have not taken a conservative approach to estimating the draft pressures needed to calculate the conductivity of the backfill material required for minimizing convective airflow. A higher value of the draft pressure was otbtained by the reviewer (25 to 300% higher than the authors') when the effects of gas compressibility and water vapor transport were included. Under-estimating the draft pressure will result in overestimating the pneumatic conductivity for the same flow rate; that is, the pneumatic conductivity of the backfill needs to smaller than that reported by the authors based on the reviewers analysis. The reviewer cannot determine how much smaller the conductivity should be because he does not have access to the resistance model used by the authors; however, the reviewer recommends that further model runs be performed by the authors in order to take into account compressibility and water vapor effects. These results should then be summarized in Section 8.4.3.2.1.4 of the SCP (p. 8.4.3-21) if they differ significantly from the authors' previous conclusions.

Section 5.0

The effects of barometric pumping and its ability to displace air or induce airflow through backfilled shafts or drifts was analyzed in section 5.0 of Fernandez and others (1988). The conceptual (analytical) model used by the authors was found to be appropriate. The boundary conditions of a relatively low frequency, low amplitude storm, a high frequency, high amplitude, torando and a very low frequency, low amplitude seasonal change in barometric pressure were found to be appropriate, but possibly too simplistic. The barometric signature often has several periodic events superimposed on one another over the same period of time. For instance, diurnal and semi-diurnal pressures can be superimposed on barometric high or lows caused by storm fronts which can be superimposed on a seasonal barometric pressure trend. Decomposing the barometric signature into seperate events makes the analysis simpler but may underestimate the effect of barometric pumping if the events are additive. The reviewer feels that the conclusions drawn by the authors are probably adequate based on the fact that convective airflow due to elevated repository temperatures appears to be the dominate driving force.

Review References

American Gas Association, Gas Engineers Handbook, 1st edition, 2nd printing, The Industrial Press, 1966.

Hartman, H.L., Mine ventilation and air conditioning, 2nd edition, John Wiley and Sons, Inc., 1982.

List, R.J., Smithsonian Meteorological Tables, 6th revised ed., 4th reprint, Smithsonian Institution Press, 1968.

CC: Barney Lewis

K. IKAUTZ
12/21/88
USGS

$T_1 = 13°C = 55.4°F \ (515.1\ °R)$

$T_2 = 23°C = 73.4°F \ (533.1\ °R)$

$T_3 = 115°C = 239\ °F \ (698.7\ °R)$

$T_4 = 13°C = 55.4\ °F \ (515.1\ °R)$

$\Delta t_J = 73.4 - 55.4 = 18\ °F \qquad \Delta t_H = 183.6\ °F$

$$\Delta H_h = 349.8 \left(\left(\frac{533.1}{515.1} \right)^{1034/53.35(18)} - \left(\frac{698.7}{515.1} \right)^{1030/53.35(183.6)} \right)$$

(9
Hari

$$= 349.8 \left((1.0349)^{1.07258} - (1.3564)^{0.10515} \right)$$

$$= 349.8 \left(1.03759 - 1.032577 \right)$$

$$= 349.8 \left(0.00495 \right)$$

$$= 1.73 \text{ in } H_2O \ (431\ Pa)$$

VIKING ... CALCULATIONS

K. TRANTZ
12/22/88
USGS

212°F = 100°C

MIXING RATIO @ 100°C = 37.32 $\frac{\text{lbm of Vapor}}{\text{MBL}}$ / 0.158 $\frac{\text{lbm of dry air}}{\text{MB}}$ = 236.2 = r_w

The saturated virtual temperature increment

$$= (T_v - T)_w = T r_w \left(\frac{1}{0.62197} - 1\right)\left(\frac{1}{1 + r_w}\right)$$

$$(T_v - T)_w = 373°K\,(236.2)\left(\frac{1}{0.62197} - 1\right)\left(\frac{1}{1 + 236.2}\right)$$

$$= 225.8\ °C$$

$\therefore\ T_{v\,100°C\,@\,100\%\,RH} = 273 + 100 + 225.8 = 598.8\ °K\ (325.8\ °C)\ (618.4\ °F,\ 1078.1$

$T_{v\,23°C\,@\,100\%\,RH\text{ and }870\,mb} = 273 + 23 + 3.66 = 299.66\ °K\ (26.66\ °C)\ (79.99\ °F,\ 539.7\ °R,$

$T_{v\,13°C\,@\,10\%\,RH\text{ and }870\,mb} = 0.1(1.87) + 0.1(1-0.1)\left(\frac{0.01093}{1+0.1(0.01093)}\right)(1.87) + 13 + 273$

$$= 0.187 + 0.001837 + 13 + 273$$

$$= 286.2\ °K = 13.188\ °C\ \left(55.74\ °F,\ 515.4\ °R\right)$$

$\Delta T_o = 79.99 - 55.74 = 24.25\ °F \qquad \Delta T_a = 562.66\ °F$

$$\Delta H_o = \frac{1819}{5.2}\left(\left(\frac{539.7}{515.4}\right)^{1030/53.35(24.25)} - \left(\frac{1078.1}{515.4}\right)^{1030/53.35(562.7)}\right)$$

HARTMAN (9-5

$$= \frac{1819}{5.2}\left((1.0471)^{0.79614} - (2.09177)^{0.03431}\right)$$

$$= 349.8\,(1.03735 - 1.025645)$$

$$= 4.1\ \text{in}\ H_2O\ \ (1021\ Pa)$$

review of:

Fernandez, Hinkebein and Case: "Selected Analyses to Evaluate the Effect of the Exploratory Shafts on Repository Performance at Yucca Mountain", SAND85-0598, DECEMBER 1988 (SAIC Reference No. 3568)

by: Keith Kersch KMKersch 23-Jan-1989

Several subjects are treated in this report. I looked only at the hydrologic aspects of the report. I also looked at the impact of this report on the design as discussed in section 8.4 of the SCP.

Because of the location of the shaft, flooding and erosion around the shaft opening are not expected to affect the ability of the facility to isolate waste (the shaft will be located in rock, with low erosion rates, and in an area where it is unlikely for surface flooding to reach the shaft entrance). Even though these scenarios are unlikely, the authors carefully examined several of them and concluded that erosion and flooding would not adversely affect the repository. This conclusion is appropriate for the scope of the work. They also concluded that free water movement in the shaft would be limited so that migration of fines would not appreciably change the conductivity of the shaft fill.

The data used in the report appear to be reasonable. Not all of the data used are cited in the report. Data used are taken from published reports of others that have been subject to full technical and peer review. Where possible data used were checked against the RIB. The value used for porosity of shaft fill was 30% which is reasonable for unconsolidated, poorly sorted fill based on my professional experience.

The analysis method was reasonable and is very similar to the approach I would have used if I had done the work.

Uncertainty is addressed by considering very unlikely scenarios and varying rock properties over wide ranges. For example, the authors examined potential of surface flooding with the exploratory shaft entrance located in alluvium when the planned location is in rock. They used a wide variation of conductivities for rock surrounding the shaft and in alluvium during the calculation of potential influx into the ES as a result of surface flooding at the old exploratory shaft location. In even the unlikely cases examined, buildup of water in the shaft was not sufficient to cause flooding of the underground facilities.

United States Department of the Interior

GEOLOGICAL SURVEY
BOX 25046 M.S. 421
DENVER FEDERAL CENTER
DENVER, COLORADO 80225

TAKE PRIDE IN AMERICA

IN REPLY REFER TO:

WBS#: 1.2.5.2.1
QA : "QA"
January 13, 1989

August Matthusen
Science Applications International Corp
Suite 407 101 Convention Center Drive
Las Vegas, NV 89109

Dear Augie:

Enclosed are four letters that were prepared as a result of reviews that were conducted as part of the Technical Assessment Review (TAR). The reviews, which were made for the TAR subcommittee on "Comparative Evaluation of Alternative ESF Locations", were used to evaluate whether appropriate conclusions are made in Section 8.4.3 of the SCP regarding the effects of the exploratory shafts on the waste-isolation capability of the Yucca Mountain site. The letters provide results of reviews that were made on parts of Section 8.4.3 of the SCP, Fernandez et al. (1988), and West (1988). I am transmitting copies to you because they may have a bearing on the findings of your subcommittee on "data reasonableness".

In general, the reviewers conclude that: 1) the models, assumptions, boundary conditions, and data inputs that were used in the analysis were reasonable and appropriate; 2) data uncertainties were considered and conservative approaches were taken; 3) the conclusions that were drawn were reasonable and appropriate; and 4) the conclusions were utilized appropriately in the judgments made of the potential impacts of the ES on performance.

The reviewers raised certain technical points that, if proven to be valid, could impact design. In addition, in some cases, additional or alternative technical approaches or models were suggested. Generally, the technical concerns raised are expected to be compensated for by the conservative measures that will be taken in design. These concerns do not reflect adversely on the Title I design approach but should be considered in Title II.

Sincerely yours,

William E. Wilson

William E. Wilson
USGS/Yucca Mountain Project

Enclosures
WEW/pnb
TAR.WEW

D-3790

JAN 6 1989

WBS #: 1.2.3.1
QA: QA

Memorandum

To: Bill Wilson, U.S. Geological Survey, Denver, Colorado, MS-421

From: Joe Prizio, U.S. Bureau of Reclamation, Denver, Colorado, D-3790

Subject: Technical Assessment Review Plan, Exploratory Shaft Facility (ESF) Title-I Design Acceptability Analysis and Comparative Evaluation of Alternative ESF Locations

On December 22, 1988, I sent to you a draft copy of my comments on section 8.4.3 of the SCP and Sandia report SAND85-0598. This memorandum is to transmit those comments formally. Feel free to contact me at extension 64175 if you have any questions.

Technical Assessment Review Plan (TAR Plan) Scope

The TAR Plan, dated December 12, 1988, contains two review objectives:

1) to evaluate the ESF Title I design against three general objectives in 10 CFR Part 60, namely:

a) the long-term waste isolation capability of the site will not be compromised;

b) the ability to characterize the site will not be compromised;

c) the ESF site-characterization activities will provide representative data.

2) to compare alternative ESF locations.

The TAR Package contains the documents to be reviewed, as well as resource documents that team members may use without "review" to support their evaluations. Examples of the review documents are the Generic Requirements Document/Appendix E; the ESF-SDRD, Volumes I and II; the Reference Information Base (RIB); the ESF Design Scope and Planning Document for Title I Design; and Control Drawing Number R07048A, Sheets, 1-15. The resource documents consist of the draft 10 CFR 60 flowdown report and section 8.4 of the SCP.

The assignment given to me on December 20, 1988, was to examine section 8.4.3 of the SCP and "review" section 3.0 and Appendices

C and D of Sandia report SAND85-0598. SCP section 8.4.3 (dated December, 1988) discusses potential impacts of site characterization activities on the repository postclosure performance objectives. Section 3.0 of Sandia report SAND85-0598 (dated December, 1988; authors: Fernandez, Hinkebein, and Case) examines whether the ESF enhances the potential for radionuclide releases during selected water flow scenarios. Appendix C contains a scenario describing fully saturated alluvial flow at the "old" exploratory shaft locations; and Appendix D contains additional information supporting the Appendix C analysis.

Three question categories were to be considered: category 1 examined whether the analyses contained in the SAND85-0598 were appropriate to determine how ES site characterization activities might affect conditions at the site; category 2 examined whether conclusions concerning how the changed conditions would affect postclosure performance were appropriate; and category 3 examined whether the same conclusions drawn in SCP Section 8.4 regarding the impact of the ESF on waste isolation were also clearly and directly presented in SAND85-0598. Please note that this assignment thus pertains to TAR review objective 1a above.

Review

Section 3.0 of SAND85-0598 evaluates whether possible water entry into the ES's and associated MPZ's (modified permeability zones created during shaft construction) could significantly enhance the radionuclide-release potential. The water source is the probable maximum flood (PMF) produced by either of two separate probable maximum precipitations, namely a local storm (thunderstorm) or a general storm.

The report evaluates various scenarios postulating water entry into the ES/MPZ's. One scenario examines whether either of the PMF's flowing down existing water courses can inundate the ES pad. Although somewhat unclear, the analysis appears to compare an "average" peak water height at a given channel cross section to the adjacent top of the ES pad. The analysis concludes that only peak flood discharges about 45 and 240 times greater than the thunderstorm discharge (the more severe of the two events) would reach the ES1 and ES2 collars, respectively.

To obtain the "average" peak water height, the analysis examines 5 channel cross sections along the length of the pad. For completeness, the analysis should state the water height at each cross section, along with its corresponding channel invert elevation.

The scope of the inundation study contained in SAND85-0598 does not address trends in topographical changes. Appendix C, however, determines the inundation and its results if the PMF were to occur sometime after an earth movement of sufficient magnitude to impound the entire flood discharge. Although the shaft-inflow results technically apply to the "old" ES locations (where saturated overburden contributed to the inflow), they could represent an upper bound case for the current ES locations. It seems to be a shortcoming that either 1) a similar analysis, including earth movement, was not performed for the current ES locations or 2) the SCP section 8.4 does not cite the appendix C study as an upper bound inflow case.

Other potential conflicts between SCP section 8.4 and SAND85-0598 section 3.0, Appendix C, and Appendix D are as follows: SAND85-0598 discusses how precipitate formation might effect ESF drainage capabilities, while no similar discussion appears in SCP section 8.4; SCP section 8.4 discusses how the separate issue of siltation might effect ESF drainage capabilities, while no similar discussion appears in SAND85-0598.

In all other respects, the analyses contained in SAND85-0598 appear valid. The range in theoretical conditions analyzed appears comprehensive. Assumptions and parameter selection appear reasonable and conservative. Conclusions appear appropriate.

cc: U.S. Geological Survey, Attention: MS-421 (L. Hayes), P.O. Box 25046, Denver CO 80225

11-Jan-1989

Joe R Tillerson

Joe R. Tillerson

Review of: Hill, J., 1985. Structural Analysis of the NNWSI Exploratory Shaft, SAND84-2354, Sandia National Laboratories, Albuquerque, NM.
(SAIC Reference # 2706)

Data Reasonableness

1. Data are not in exact agreement with the RIB (version3.0) but are sufficiently close in most areas. I consider that the data used are reasonable for Yucca Mountain with the following exception. The value used for the Young's Modulus (26.7 GPa) is reasonable for use as a matrix value but not for a rock mass value considering that the Topopah Spring tuff is relatively fractured.

2. I do not believe that the use of the matrix value for Young's Modulus (see above) significantly impacts the conclusions reached in the report.

The use of the matrix value for the modulus is not likely to significantly impact the predicted stresses near the openings since the stresses near an opening are virtually independent of the modulus of the material in an elastic analysis. Since the stresses and related factors of safety formed the basis for most of the conclusions in the report, it is unlikely that the conclusions would be changed by using a more appropriate modulus.

3. If displacement values are quoted from this report, they should be caveated since it is likely that the displacements predicted here are about a factor of 2 lower than what should be anticipated in Topopah Spring tuff.

I think that the use of the matrix value for the modulus makes the model relatively "stiff" and would therefore lead to an underprediction of the displacements. Since the displacements vary linearly with the modulus in a linear-elastic analysis, it is likely that the displacements predicted by the model are lower than those that should be anticipated. The ratio of the matrix value of the modulus (about 27 GPa) to the rock mass deformation modulus (about 15 GPa in RIB 3.0) suggests that the displacements are off by about a factor of 1.8.

Reasonableness of Analysis Method

1. The methods used in simulating the response of the openings are reasonable considering the preliminary nature of the calculations.

The author clearly identified the analysis method, the computer code used (SANDIA-ADINA), and assumptions (2-D, 3-D, linear-elastic, etc.). It appears that analysis methods and assumptions appropriate for simulating the response of openings in Topopah Spring tuff have been used.

11-Jan-1989

Treatment of Uncertainty

1. I believe that the author has appropriately considered uncertainty in the preliminary calculations documented in SAND84-2354.

Uncertainties were addressed explicitly and implicitly in the evaluations. They were addressed by the use of both 2-D and 3-D simulations and by judgments made by the author regarding the fact that relatively high factors of safety (above 4) exist in the pillars. He evaluated whether or not the pillar widths are acceptable and provided some insight into the effects of crossection shape (i.e. one analysis used a square opening while another had a "horseshoe-shaped opening). In my opinion the author tended to overstate one conclusion regarding, "even if all the worst possible conditions existed ..., the drifts would still be safe." I nevertheless believe that the analyses reported indicate that, in general, stable openings would be expected in the ESF and that pillar widths are acceptable if the conditions encountered underground are near to those expected based on the available data.

Appropriateness of Analysis use in ESF Title I Design Evaluations

1. I believe that the analyses have been appropriately used in the design evaluations in SCP Section 8.4.

The analyses in this report are referenced as one of several analyses that provide a basis for estimating the extent of the stress changes that occur near drifts and alcoves. The discussion in the SCP concluded that a 2-diameter standoff distance is sufficient to account for the stress-altered zone around the opening considering that the analyses generally show that stresses are within 10 percent of the initial in situ stresses beyond one drift diameter. This is also one of the documents that can be considered to support the standoff between the ESF and the repository. The analysis is also summarized in a discussion of the effects of drift shape and pillar width on stability.

Recommendations: Authors using this report in future evaluations should indicate recognition of the fact that a rock matrix value was used in the simulations for the elastic modulus.

Review of:

Hopkins, Eaton, and Sinnock: "Effect of Drift Ventilation on Repository Hydrology and Resulting Solute Transport Implications", (1987) SAND86-1571, (SAIC Reference No. 2306)

By: Keith M. Kersch KMKersch 23-Jan-1989

The principal contribution of this work to the design of the exploratory shaft is a statement in the new SCP under section 8.4.3.2.1 that water introduced during drilling will be removed within a few years by evaporation caused by ventilation. This use of the report is reasonable and an appropriate application of the results. The total impact of this study is that sinking of the exploratory shaft will not have much impact on the experiments to be conducted there.

The assumptions made in this report appear to be reasonable. Conservative assumptions were made in many cases.

The calculational approach was reasonable and conservative. The effects of the waste package heat drying the repository rock was not considered which is extremely conservative. These results show that ventilation alone will dry the rock considerably.

Uncertainty in the data is addressed by making calculations for downward fluxes of .5 and .1 mm/year. The calculations were made assuming that the relative humidity in the emplacement drifts would be 90% in the 2D calculations and 96% in the 1D calculations, which is probably conservative. The effects of waste package heat drying the rock was not included in the calculations, which is extremely conservative for the emplacement drifts but will not affect the exploratory shaft.

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Charles F. Voss 1/23/89

Reviewer: Charles F. Voss   Date: January 20, 1989

Document Reviewed: Hustrulid, W., 1984. "Lining Considerations for a Circular Vertical Shaft in Generic Tuff," SAND83-7068, Sandia National Laboratories, Albuquerque, NM.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (Version 3.0)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 3.0 Reference Information Base

Version 3.0 of the RIB was reviewed as part of the TAR and an assessment was made of the reasonableness of the data. The review was performed by several TAR members based on their technical area of expertise and familiarity with properties of the Yucca Mountain site. Specific comments concerning the reasonableness of the RIB values are contained in the review of the RIB included in Appendix I.

2. Appropriateness of the data and parameters used in the analyses

The author used "generic" tuff properties based on Lappin (1982) who reported average mechanical properties of the tuffaceous beds and the welded devitrified Tram and Bullfrog members. The properties used are similar to the values reported in the RIB. A Mohr-Coulomb failure criteria was assumed for the rock mass surrounding the shaft. The requisite parameters for the criteria are consistent with those in the RIB. Because the values from Lappin (1982) are from laboratory tests using intact samples, the rock mass behavior was considered by applying strength reduction factors to the failure criteria. Finally, the relationship describing the in situ stress state is consistent with the expression given in the RIB. Overall, no significant data inconsistencies were noted.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

Classical formulas were used in the calculations. The cases evaluated considered the stress conditions at significantly greater depths than the proposed repository at Yucca Mountain. In addition, the analyses assumed the shaft was drilled. Both elastic and elastic-plastic models were used to evaluate possible rock conditions and the rock mass response around the shaft with different liner thicknesses and emplacement scenarios. Case history data from a shaft constructed in a shale and sandstone formation was used to evaluate the analytical methods considered in the report. The 5 m diameter shaft was sunk to a depth of 1000 m using the drill and blast method. Differences between the measured field data and the analytical results were considerable and the author concluded the theoretical analyses appear to provide exceptionally conservative estimates of the rock mass response.

4. Consideration of data uncertainty

Data uncertainty was considered in the analyses by varying the strength reduction factor applied to the Mohr-Coulomb strength criteria and by considering both wet and dry properties (the wet condition properties represent conservative values). In addition, a number of cases were analyzed assuming different liner emplacement scenarios.

5. Use of the analyses to form conclusions in 8.4

The only conclusion stated in 8.4 that appears to be based on this report concerns the apparent conservativeness of the analytical method based on the comparison between the predicted liner response and that observed in a case history study. This conclusion was stated by Hustrulid in the report and is supported by the data presented.

Conclusions: Based on my review of the referenced document, I consider the data used and the analytical methods appropriate and consistent with the objectives of the report and the current understanding of the site conditions. The use of this report in Section 8.4 to support the conclusion that the rock mass failure zone around a shaft in the Topopah Spring tuff (TSw2) is not expected to extend far into the rock wall based on the apparent conservativeness of the analytical method used and is judged to be reasonable when considered with the other report by Hustrulid (1984b) referenced in 8.4.

Recommendations: None.

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT

Charles F. Voss 1/28/89

Reviewer: Charles F. Voss Date: January 20, 1989

Document Reviewed: Johnson, R.L., 1981. "Thermo-Mechanical Scoping Calculations for a High Level Nuclear Waste Repository in Tuff," SAND81-0629, Sandia National Laboratories, Albuquerque, NM.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (Version 3.0)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 3.0 Reference Information Base

Version 3.0 of the RIB was reviewed as part of the TAR and an assessment was made of the reasonableness of the data. The review was performed by several TAR members based on their technical area of expertise and familiarity with properties of the Yucca Mountain site. Comments concerning the reasonableness of the RIB values are contained in the review of the RIB included in Appendix I.

2. Appropriateness of the data and parameters used in the analyses

The analyses performed are scoping analyses performed for the Tuff Mine Design Study during fiscal year 1980. Two different gross thermal loading cases were analyzed given two different assumed design criteria: boiling of the ground water; and no boiling. The assumed depth of the repository was 800 m and, therefore, the vertical stress is much greater than at the 300 m depth of the conceptual repository. The horizontal-to-vertical stress ratio assumed at the

800 m depth is 0.65. The mechanical property values used are similar to the Topopah Spring nonlithophysal values in the RIB except for the intact and joint internal angle of friction which are somewhat greater than the values contained in the rib. The high friction angle results in greater rock mass strength. However, the assumed stress conditions more than compensates for the higher friction angles used.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

The rock behavior was modeled using a ubiquitous jointed rock model which allows slip along randomly oriented joints. Initiation of slip along joints and initiation of intact rock failure in the model is base on a Coulomb failure criterion. Intact rock that failed more than once was assumed to have material properties of a granular material. The models were simplified two-dimensional representations of an emplacement room having vertical emplacement holes. As mentioned above, the model assumed a repository depth of 800 m with a resulting stress field much greater than the estimated stresses at the proposed repository level (approximately 300 m). Assuming the rock failure criterion is appropriate, the extent of the failed zone would be considerably greater than at 300 m. Based on this difference, use of the model to support the analyses of the potential impacts of site characterization activities on performance objectives is considered conservative.

4. Consideration of data uncertainty

Data uncertainty is not considered in the analyses. The rock properties assumed in the analyses were specified by the MIDES Working Group.

5. Use of the analyses to form conclusions in 8.4

The Johnson (1981) reference is discussed in section 8.4.3 (p. 8.4.3-27) in the discussion on predicted thermal stresses and displacements. The only comment concerning the analyses pertains to the extent of the zone where the combined stresses were sufficient to cause intact rock failure. Given the assumed stress state conditions in the analyses, the results are considered conservative.

Conclusions:

The analyses were performed in 1981. The material properties used and the assumed conditions were assigned by in a "Mine Design Working Group - Activity Work Package (1979)" and it is assumed that the values were appropriate given the data available at that time. Regardless, the values are similar enough to the Topopah Spring tuff (welded, nonlithophysal) for use as a comparison. The rock properties used are generally within the ranges of values provided in the RIB. The high stress conditions assumed in the model over predict the extent of intact rock failure that would be expected around openings at the shallower levels considered in section 8.4.3. The reference is not used to support any major conclusions or positions concerning possible impacts of site characterization on site performance.

Recommendations:

None.

11-Jan-1989

Joe R. Tillerson

Joe R. Tillerson

Review of : Johnson, R. L., and S. J. Bauer, 1987. Unit Evaluation at Yucca Mountain, Nevada Test Site: Near-Field Thermal and Mechanical Calculations Using the SANDIA-ADINA Code, SAND83-0030, Sandia National Laboratories, Albuquerque, NM. (SAIC Ref. No. 2001)

Data Reasonableness

1. Based on my knowledge of the site properties and the comparisons I made of values used in the analyses with those in the RIB, I believe the data used in this report are reasonable for simulating the behavior of openings in YUCCA MOUNTAIN except that a reduced (rock-mass) modulus should have been used instead of the matrix value.

The data used are not always in exact agreement with the RIB but are certainly reasonable considering the variability in the existing data.

2. For the relative comparisons made in this report for opening stability, it is unlikely that the use of the matrix value for the modulus impacted significantly the conclusions drawn in the report.

The above statement is based on the fact that the stresses in these models are virtually independent of the modulus, a wide range of moduli were considdered (e.g. the limit value for the modulus of the Calico Hills is less than 1/4 of the average value for the Topopah Spring), and the stability conclusions were that stable openings could be anticipated even for the wide range of properties considered.

Reasonableness of Analysis Methods

1. While it is possible to use more sophisticated analysis methods, the analysis method chosen is reasonable and appropriate for evaluating the stability of underground openings at Yucca Mountain.

The ubiquitous joint model was used in the ADINA code. The model was described briefly in the report and references given to where more detailed information could be found. The ADINA code has been widely used for structural calculations in many fields. The authors evaluated the potential for both matrix failure and for slip along existing joints.

Treatment of Uncertainty

The authors effectively treated uncertainty by analyzing the stability of repository openings using both average and limit properties for both the Topopah Spring tuff and the Calico Hills member. In situ stress conditions were also varied substantially in the investigations.

11-Jan-1989

Appropriateness of Analysis use in ESF Title I Design Evaluations

1. I believe that the analyses have been appropriately used in the design evaluations in SCP section 8.4.

The document is appropriately referenced as one of several analyses that provide a basis for estimating the extent to the stress-altered sone around the opening considering that the analyses generally show that stresses are within 10 percent of the initial in situ stresses beyond one drift diameter. This is also one of the documents that can be considered to support the standoff (related to mechanical effects) between the ESF and the repository drifts. It should be noted that the stress plots do not appear in this document but the factor of safety plots and the joint slip plots can be interpreted to support the standoff statements.

Recommendations: When referenced in future reports, cognizance of the fact that a rock matrix value was used for the elastic modulus should be demonstrated.

11-Jan-1989

Joe R. Tillerson

Joe R. Tillerson

Review of: Johnstone, J.K., R. R. Peters, and P. F. Gnirk, 1984, Unit Evaluation at Yucca Mountain, Nevada Test Site: Summary Report and Recommendation, SAND83-0372, Sandia National Laboratories, Albuquerque, NM. (SAIC Ref. # 951)

Data Reasonableness

1. Data are not in exact agreement with the RIB (version 3.0) but are sufficiently close in most areas. I consider that the data used are reasonable for Yucca Mountain with the following exception. The values used for the Young's Modulus for the various units are reasonable for use as matrix values but not for rock mass values, particularly for units such as the Topopah Spring that are relatively fractured.

2. I don't believe that the use of the matrix values for the modulus (see above) significantly impacts the conclusions reached in the report.

The use of the matrix value for the modulus is not likely to significantly impact the predicted excavation-induced stresses near the openings since the stresses near an opening are virtually independent of the modulus of the material in an isothermal, elastic analysis. Since the stresses and related factors of safety formed the basis for most of the conclusions in the report, it is unlikely that the conclusions would be changed by using a more appropriate (lower) modulus. When thermal effects, are considered, it is likely that the higher modulus resulted in higher stresses; however, since the thermal loading for each unit evaluated in the study was practically the same, the relative comparisons of opening stability after repository heating should remain valid. Additionally, since the conclusion was reached that the heated opening in the Topopah Spring tuff would be expected to be stable, the fact that higher stresses were predicted than would likely be experienced provides additional confidence that the opening would be stable.

Reasonableness of Analysis Method

1. The methods used in simulating the response of the openings are, I believe, reasonable considering the available data and analysis methods.

The authors clearly identified the models and codes used in the thermal and thermomechanical analyses (ADINAT, SPECTROM-41, SANDIA-ADINA, SPECTROM-11).. The authors provide references where more information on the codes can be found and identify the geometry modeled, the initial and boundary conditions simulated, and the heat charcteristics of the waste. Continuum elastic/plastic stress analysis codes simulating ubiquitous vertical joints were used. Additionally, rock mass classification approaches were used to provide additional relative comparisons of the anticipated stability of openings in the four units. Both the continuum-type models and the rock mass classification approaches are used often in industrial or other geomechanics evaluations.

Treatment of Uncertainty

1. I believe that the authors have appropriately considered uncertainty in the calculations documented in SAND83-0372.

The report is one of the better examples of effective consideration of uncertainty that has been produced to date in the Yucca Mountain Project. A rather wide variety of properties were used in the analyses; specifically, both average and limit values were used for each of four different units. The net effect is that opening stability calculations are available over a very wide range of thermal and mechanical properties and that all the calculations indicate that stable openings should be expected at Yucca Mountain. Ranges of values are greater than factors of 3 for the modulus, 2 for the thermal conductivity, 2 for the thermal expansion and 4 for the unconfined compressive strength. Furthermore, the authors provided more insight into the potential credibility of the calculations (and thereby attempted to reduce the uncertainities related to their interpretation) by comparing the calculated results for Yucca mountain with those predicted for G-tunnel. Since the G-tunnel results are similar to the results from the Yucca Mountain formations and G-tunnel drifts are stable, the authors conclude, appropriately in my opinion, that predictions of motion along joints do not necessarily imply instability. Finally, the authors reduced uncertainty in the use of their results by comparing the results of tunnel indexing methods applied to G-tunnel and Yucca Mountain formations. They concluded that the Topopah Spring and G-tunnel tuffs had similar indexing characteristics; hence, it can be inferred that opening stability or support requirements would be similar.

Appropriateness of Analysis Use in ESF Title I Evaluations

1. I believe that the analyses have been appropriately used in the design evaluations in SCP Section 8.4.

In a section (8.4.3.2.3.1) that discusses predictions of thermal stresses and displacements, the analyses are referenced as one of several evaluations that have been completed to date of opening stability. The ubiquitous joint model was appropriately referenced and it was indicated that limit and average properties were used. Appropriate reference was made to the extent of matrix fracturing and joint slip predicted and to the comparisons with G-tunnel test results and model predictions.

Recommendations: None

NOTE: GWTT calculations were also documented in the report but were not reviewed here because those calculations have not been referenced in the evaluations related to ESF Title I design.

TECHNICAL ASSESSMENT REVIEW COMMENT RECORD

Sheet 1 of 5

TECHNICAL ASSESSMENT REVIEW SUBJECT: ESF TITLE-1-DESIGN ACCEPTABILITY ANALYSIS, PART I-ELEMENT 4: ASSESSMENT OF APPROPRIATENESS OF DATA USED AND TREATMENT OF UNCERTAINTY

REVIEWER(S) Ralph Cady ORGANIZATION DOE/HQ

TOPIC AIR AND WATER-VAPOR FLOW (SCP p. 8.4.3-20)

REFERENCE Kipp, Jr., K.L., 1987. "Effect of Topography on Gas Flow in Unsaturated Fractured Rock: Numerical Simulation," American Geophysical Union Geophysical Monograph 42, D.D. Evans and T.J. Nicholson (eds.), pp. 171-176.

COMMENTS This reference is used by the SCP to suggest that large-scale air movement within Yucca Mountain ~~may~~ occur. The reference reports scoping simulations that are inherently uncertain due to model simplifications and parameter uncertainties. Model was ~~RECOMMENDATIONS~~ not tested against observations, but the model and data were appropriate for scoping purposes and citation in the SCP.

RECOMMENDATIONS: None

Ralph Cady 1/23/89

DATE REVIEW COMPLETED 1/3/1989 SIGNATURE Ralph Cady

3-1370

Review of:

Kipp (1987): "Effect of topography on Gas Flow in Unsaturated Fractured Rock: Numerical Simulation," American Geophysical Union Geophysical Monograph 42

By: Keith M. Kersch Keith M Kersch 23-Jan-1989

This report presents the results of some numerical simulations of topographically induced air flow at Yucca Mountain. Not much use of this report is made in the design of the ESF. The only reference to this work in the SCP is on page 8.4.3-21, which concludes that the calculated water-vapor transport out of the mountain is very small, probably due to model simplification and parameter uncertainty.

The approach and the assumptions used are reasonable for a scoping calculation.

The data used are reasonable. Where possible, the data were checked against values in the RIB. Correlations in the Fluids Pak for the Hewlett-Packard 41C calculator was used to calculate a value of about two-thirds the value in the report for viscosity of air. The heat capacity of air seems too high by a factor of 3 compared with values found in the 39th edition of the Handbook of Chemistry and Physics (Chemical Rubber Publishing Company). The uncertainty in the permeability (the assumed values seem reasonable) will overshadow the inaccuracies in the other assumptions, so I feel the general approach is reasonable.

Uncertainty in the data values are not treated in this report. Since this is a conceptual calculation with no impact on the design, I don't feel that addressing uncertainty was necessary.

review of:

Kwicklis and Hoxie: "Numerical Simulation of Liquid-Water Infiltration into a Fractured Welded Tuff." (abstract) USGS, (SAIC Reference 2879)

by: Keith Kersch Keith Kersch 20-Dec-1988

This report is an abstract and contains no data.

TECHNICAL ASSESSMENT REVIEW COMMENT RECORD

Sheet 1 of ____

TECHNICAL ASSESSMENT REVIEW SUBJECT: ESF TITLE-1-DESIGN ACCEPTABILITY ANALYSIS, PART I-ELEMENT 4: ASSESSMENT OF APPROPRIATENESS OF DATA USED AND TREATMENT OF UNCERTAINTY

REVIEWER(S) Ralph Cady ORGANIZATION DOE/HQ

TOPIC Groundwater flow in matrix & fractures.

REFERENCE Kwicklis, E.M., and D.T. Hoxie, 1988. Numerical simulation of Liquid-water Infiltration into an Unsaturated, Fractured Rock Mass. (attached) ~~[illegible]~~ NN1.881202.0018

COMMENTS (see attached)

RECOMMENDATIONS If this analysis is relied upon heavily, far greater detail should be provided, and symmetry question should be addressed when applying results to infer things regarding invasion of drilling fluid

DATE REVIEW COMPLETED 12/22/88 SIGNATURE Ralph Cady

KNICKLIS & HOXIE, 1988   NN1.881202.0018

Ralph Cady
12/23/88

STATEMENT OF DATA REASONABLENESS:

While explicit data on parameter values were often not listed in this abstract, those that were provided are reasonable given the present state of knowledge on welded tuff at Yucca Mountain.

STATEMENT ON REASONABLENESS OF ANALYSIS METHOD:

SPECIFICS of the methods were not provided in sufficient detail in this abstract to allow a determination of reasonableness. The conceptual model, as described, seems reasonable & appropriate for the analysis.

STATEMENT ON TREATMENT OF UNCERTAINTY:

UNCERTAINTY was only considered relative to the size of the fracture aperture, it was varied one order of magnitude (from 25 micrometers to 250 micrometers). Sensitivity of the system response to other uncertainties was not evaluated.

STATEMENT ON APPROPRIATENESS OF USE OF ANALYSES IN SCP section 8.4:

Simulations described in the abstract treated the vertical infiltration of ponded water. The SCP section purported to infer something about effects from drilling fluid on fracture-matrix saturation. These different problems have different symmetry; invasion of drilling fluid would commonly be radially symmetric about a vertical axis. This inconsistency may not radically effect the results in a scoping sense but would be expected to significantly impact the numeric results

CJNoronha 1-27-89

TECHNICAL ASSESSMENT REVIEW SAND85-2701
PART I - ELEMENT 4

Reviewer: Clifford J. Noronha Date: 27 January 1989

Document Reviewed: Lin, Y.T., M.S. Tierney, 1986. "Preliminary Estimates of Groundwater Travel Time and Radionuclide Transport at the Yucca Mountain Repository Site", SAND85-2701, NNWSI, Sandia National Laboratories, Albuquerque, NM. (SAIC Reference Number: 3798)

Reasonableness of the Analyses

The subject report demonstrates the use of a probabilistic approach to the calculation of distributions of ground-water travel times and resulting cumulative radionuclide releases to the water table beneath Yucca Mountain.

The conceptual model (Figure 7) consists of 963 vertical, square columns of stratigraphic units extending from the boundary of the disturbed zone (50 m below the repository) down to the water table. The hydrogeologic units are shown in Figure 2, where the subscript "w" is for welded and signifies low conductivities. The subscript "n" is for non-welded and signifies high conductivities, unless it is followed by "z" for zeolitized in which case the conductivity is low.

The mathematical formulation of the travel time calculations is a simple application of steady-state, unsaturated Darcy flow under a unit vertical hydraulic gradient. In most hydrologic models, there is inevitably a trade-off between mathematical and geometric complexity. Using an upper-limit, conservative value of 0.5 mm/yr for the percolation flux, the mean ground-water travel time is found to be about 43,000 years which more than adequately satisfies the 1000 yr or even 10,000 year regulations.

The radionuclide transport is based on the above travel times. The mathematical formulation assumes advective transport of a single decaying species subjected to retardation. The source boundary condition is a decaying-band release beginning at a breach time, Tc. Using a Laplace transformation, the concentration and cumulative discharge of each radionuclide to the water table are evaluated by a computer code (Appendix C-2). Table 4 shows that during the first 10,000 years, only the unretarded nuclides, C14, I129, and Tc99 contribute to the release. Based on a repository inventory of 70,000 MTHM, the total curie release is about 1E-7 of the EPA standards in 40 CFR 191.

I believe that the analyses carried out are appropriate and the approach used is reasonable.

1-27-89

Reasonableness of Data

The independent parameters used in these calculations are:

- thicknesses of each hydrogeologic unit
- percolation flux (q),
- effective matrix (ne) and fracture (nf) porosities
- saturated matrix hydraulic conductivity (Ks)
- Brooks-Corey exponent (>1) for relative conductivity

The Reference Information Base (Version 3.0) contains no hydrologic data. Most of the data used in this report for the travel time calculations are summarized and compiled in Table 1. Various parameter values are given for the seven different hydrogeologic units being considered in this report.

I found that this table had been reproduced in Table 6-18 of the Yucca Mountain EA. In the SCP, Table 3-26 contains some of this type of data. Porosity values compared reasonably well between various references. Because of its significance to even steady-state flow calculations, I focused my attention on the mean saturated hydraulic conductivity values, Ks. While TSw and CHnz were within the same order of magnitude between the Table 3-26 of the SCP and the subject report, the CHnv value of 2.7E-7 m/s in Table 3-26 was almost two orders of magnitude higher than the 107 mm/yr (3.4E-9 m/s) reported in this report.

Upon examining the Ks values of the Prow Pass and Bull Frog units which are below the water table, I could not understand why the welded values were greater than the non-welded ones. Usually, the opposite is true. All other data values in Table 1 look reasonable. The remark accompanying the values of the Brooks-Corey exponent, follows from Equations 11 and 12.

Most of the data in Table 1 originated from the Tuff Data Base (TUFFDB). In their raw form, these extracted data are tabulated in Appendix B. In Table B-1, the standard deviations of matrix porosity, nb, for PPn and BFw should be divided by 10. For BFn, both mean and standard deviation do not agree with the raw data and should be 0.204 and 0.039 respectively. I spot checked the conversions from Tables B-1 and B-5 to Table 1 and they looked good.

With the above exceptions, the other data in the subject report are reasonable and appropriate.

Treatment of Uncertainty

The authors have addressed uncertainty adequately in their choice of the wide range of input parameters. Section 2.4 describes a baseline case and four other cases which investigate the variations in correlation length (vertical discretization), percolation flux, saturated hydraulic conductivity, and effective porosity. The authors conclude that the travel time distribution is most sensitive to flux, conductivity and discretization and less to porosity.

APPENDIX K

Supporting Documentation for Comparative Evaluation of Explatory Shaft Location

Horanski 1-27-89

Use in SCP Section 8.4

As pointed out earlier, the data from Table 1 in this report is reproduced in Table 6-18 of the NNWSI EA, but could only be compared against data in Table 3-26 of the SCP. During this review, our primary focus was Section 8.4 of the SCP, but if appropriate information was not found in this section, we looked for it in other documents. Therefore, since this data is compiled in the EA, the conclusions drawn in it, are based on the use of these specific data values. Different data would undoubtedly result in different conclusions.

The discussions in SCP Section 8.4 are an accurate summary of the significant conclusions drawn in the subject report.

Editorial Comments

Page 33 was inadvertantly repeated on page 44. This should be rectified at the next opportunity.

review of:

Mario J. Martinez: "Capillary-Driven Flow in a Fracture Located in a Porous Medium", SAND84-1697 (SAIC Reference No. 3804)

by: Keith Kersch *Keith Kersch* 20-Dec-1988

The data used in the report appear to be reasonable. RIB version 1 was used for many parameters. Other values were taken from publications that have been reviewed extensively for technical adequacy. Some values compared well with RIB version 4 which is not yet released.

The analysis methods in this report are appropriate for the intent of the report. The analysis method used is based on equations that have been published previously and subject to full technical and peer scrutiny.

Uncertainty is addressed in this report by using a range of values for ambient saturations and fracture aperture. The values used cover a wide range of values. Fracture apertures were studied from 25 to 100 microns. Some authors feel that apertures are of the order of 15 microns (Peters, et al. 1984). Penetration distances predicted are greater than anticipated, and therefore conservative.

The results from this report are appropriately used in section 8.4 of the SCP during discussion of the waste package environment, and in the effects of drilling and sinking of the exploratory shaft. The actual depth of altered water content around the waste package will have little effect on the design of the ESF. The estimated maximum (which is conservative) depth that water used in sinking of the ESF will penetrate is about 10 meters. This should not interfere with any experiments to be conducted more than 10 meters away from the shaft.

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Reference: Nimick, F.B., L.E. Shephard, and T.E. Blejwas, 1988. "Preliminary Evaluation of the Exploratory Shaft Representativeness for the Yucca Mountain Project", SAND87-1685, Sandia National Laboratories, Albuquerque, NM.

Reviewer: Richard Lee

Summary of the Data Review Process Used as per TAR Plan Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (version 3.0)

2. the appropriateness of the data parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR 60.

1. Reasonableness of the data in the RIB (version 3.0)

Nimick et al. (1985), hereafter referred to as the authors, discuss the representativeness of a variety of parameters that were at issue in the evaluation of the ESF location. These parameters include geology, mineralogy, rock mechanics, the waste package, repository design, and performance assessment. The final evaluation of representativeness of each parameter was parsed into three categories: (1) "representative"; (2) "inconclusive"; and (3) "nonrepresentative". This review is limited to conclusions reached on those parameters referenced in section 8.4 of the SCP and credited to authors: unit thickness, lithophysal abundance, overburden thickness and vertical in situ stress, grain density, matrix porosity, geomechanical intact rock properties, and ground support requirements.

The authors referenced data reported by Ortiz et al.,(1985), from which the USW G-4 bore-hole geological, thermal, and mechanical stratigraphy were abstracted. The RIB values include the "faulting correction" and the effects of vertical deviation on the estimated unit elevations. Those values reported by the authors for USW G-4 are reasonably consistent with the RIB. Other bore hole data were not checked for consistency with cited references; it is reasonable to assume that uncertainties of measured unit thicknesses are considerably less than the uncertainties associated with the model interpolated values at other locations within the proposed repository area. The stratigraphic unit data compiled from the bore holes include up to 16 identifiable thermal/stratigraphic units. The fault data, including dip, and vertical offset, were taken from Ortiz et al.(1985).

Stratigraphic unit data were compiled from bore holes USW G-1, USW G-2, USW GU-3, USW G-4, and UE-25a #1. Only USW G-4 is within the boundary of the underground facilities; G-1 and G-2 provide control to the north; USW GU-3 provides control to the east.

2. Appropriateness of the data parameters used in the analyses

The data parameters appear to be perfectly adequate for this analysis. The authors have been careful to point out their assumptions, and when additional data becomes available, the model can correspondingly develop in sophistication to include variable orientation of faults, and degree of fault offset. At present, there is insufficient data to justify additional parameterization of the model.

While the data parameters appear to be appropriate for this study, it appears that additional data could have been taken from the work by Ortiz et al.(1985). It is possible that the addition of data from drill holes USW H-3, USW H-6, USW H-4, and USW H-5, could provide additional control for some units in the interpolation. We acknowledge that although the stratigraphy from these holes were estimated from bore hole cuttings, and thus unit depths are uncertain to a larger degree, depth control for some of the geologic units could have been achieved.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

The stratigraphic modeling technique is based on the methodology described by Ortiz et al., 1985. The model is a three dimension geometrical representation of the stratigraphic, mineralogical, and hydrological layers in Yucca Mountain. The model incorporates data on unit thickness and depth from selected drill hole logs. Fault maps (Scott and Bonk, 1984) are used to identify faulting planes through the blocks, in addition to the their orientation, amount of offset, and style of faulting. Topographic and geologic maps are used to construct the surface of the model.

The fault data are used to remove offsets in the block model; transforming the bore hole x,y, and z coordinates in order to construct smooth model planes ("prefaulted coordinates"). Least squares methods are used to define an analytic plane for each stratigraphic layer. The final geologic reconstruction is done by iteratively recreating fault offsets through the analytic planes. The model is based on the assumption that deposition of the units occurred uniformly, producing continuous plane layers. It is additionally assumed that potentially undetected geologic phenomena associated with erosion, volcanism and deformation associated with hidden faults do not constitute serious errors.

Fault offsets are assumed to be continuous and constant through the model.

The conceptual model is adequate for the limited amount of data available for the analysis.

4. Consideration of data uncertainty

There was no consideration of data uncertainty in the model, nor was there any need for it. The reason for this is that the interpolated structure is grossly under-determined, and thus, considerably larger errors are associated with the interpolated parameter values, as compared to the uncertainty of the input data. One way the authors could explore the validity of the assumptions made in the analysis, is to report the degree of fit of the analytic plane to the observations.

5. Use of the analyses to form conclusions in Section 8.4

The primary conclusion in Section 8.4 credited to Nimick et al., was that according to collected bore hole data, the ESF location is representative of the site area for the following characteristics: unit thickness, lithophysal abundance, overburden thickness and vertical in situ stress, grain density, matrix porosity, geomechanical intact rock properties, and ground support requirements.

Of the conclusions credited to the authors in Section 8.4, all are consistent with their conclusions, except that the authors definition of representativeness does not appear in Section 8.4.

It is important to understand the definitions of representativeness used by the authors. Four definitions were used depending on the parameter category, and the abundance of data: (1) "a value close to a presently observed mean value; (2) a set of values spanning a large portion of the existing range of values; (3) a value anywhere within the existing range of values; and (4) any value that is not anomalous". In general, inferences on data reasonableness were determined from observations of one or more of the five core holes at Yucca Mountain: UE-25a#1, USW G-1, USW G-2, USW GU-3, and USW G-4, and surface geology, and topography.

The representativeness of the stratigraphic units were evaluated by comparing the estimated ES-1 unit thickness with a histogram of unit thickness compiled from the 250 nodes of the interpolating grid. Using this procedure and the working definition of representativeness, all stratigraphic units were considered reasonable except for unit TSw3, which was considered to be "Inconclusive". This reviewer disagrees with the "representative" conclusion of units CHn1, CHn2, and Chn3; these units were estimated to have zero thickness at ES-1. The authors argue the reasonableness of these units on the basis that they are not anomalous. Their calculations indicate that the ESF would not explore the vitric dominated zones of the Calico Hills, and thus it would seem to not be representative of the unit. It is important to note, however, that according to the authors calculations, no other single location for the ESF would provide more representative data for this unit.

Conclusions:

Based on the limited data available to the authors for their analysis, the methodologies they used seem appropriate. With the exception of a few points mentioned above, the authors conclusions seem appropriate. The report carefully points out all assumptions pertaining to the analysis, but the authors fail to provide any insight of the model uncertainties.

Recommendations:

The authors definition of representativeness, should accompany the reference to the authors work in Section 8.4.

Richard C. Lee

1/6/89

Noronha 1-27-89

TECHNICAL ASSESSMENT REVIEW SAND88-2784 #3
PART I - ELEMENT 4

Reviewer: Clifford J. Noronha Date: 27 January 1989

Document Reviewed: Peters, R.R., 1988. Hydrologic Technical Correspondence in Support of the Site Characterization Plan", SAND88-2784, NNWSI, Sandia National Laboratories, Albuquerque, NM. (SAIC Reference Number: 3934)

MEMORANDUM 3: NNWSI Hydrologic Analysis Number 9

1-D Hydrologic Calculations Concerning Ground-Water Travel Time for the Repository as a Result of Water Redistribution Caused by Repository Heating

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Reasonableness of the Analyses

This memo investigates the effect of repository heating which would tend to repel, and therefore accelerate the downward movement of water below the repository.

The conceptual model consists of a vertical, one-dimensional column of only the portion of the unsaturated zone between the repository and the water table. The column extends from the water table (0.0 m) up to the bottom of the repository horizon (~220 m). The two relevant hydrogeologic units are shown in Figure 1, where, in the abbreviated, unit-naming convention, the subscript "w" is for welded and signifies low conductivities. The subscript "n" is for non-welded and signifies high conductivities, unless it is followed by "z" for zeolitized in which case the conductivity is low.

This analysis was simulated using the mathematical formulation embodied in the TOSPAC code. The initial condition corresponded to a downward percolation rate of 0.1 mm/yr (3.17E-12 m/s). To replicate the increased movement of water which would be induced by a heated repository, a downward flux of 11 mm/yr (3.49E-10 m/s) was imposed during the first 90 years. After this time, the flux was essentially returned to the initial condition. Two slightly different variations as defined in Table 2 were analyzed.

Tracer particles were introduced at 10 m intervals along the column throughout the duration of the simulation and their travel times to the water table were analyzed and plotted in Figures 12 and 13. The simulations were repeated without the thermal effects i.e. constant 0.1 mm/yr throughout the simulation. For example, in this latter case the travel time to the water table of a particle released at the top would be 400,000 years. The travel times in Figures 12 and 13 were then normalized (divided by) the unaffected travel times and then plotted in Figures 14 and 15.

I believe that the analyses carried out are appropriate and that the approach used is reasonable.

Hloraahs 1-27-89

Reasonableness of Data

The Reference Information Base (Version 3.0) contains no hydrologic data. Most of the raw data used in this memo are summarized and compiled in Table 1. The table is divided into matrix and fracture properties. Within each section, various parameter values are given for the two different hydrogeologic units being considered in this memo. These data correspond to the drill hole USW G-4.

I found that some of these values had been reproduced in Table 3-26 of the SCP. However, the Kmb value for CHnz of 2E-11 m/s (1.73E-6 m/d) was a little below the range given in Table 3-27 of the SCP. Another source of these data was found to be Table 6-18 of the Yucca Mountain EA. Porosity and conductivity values compared reasonably well between various references.

A discrepancy noted at the end of Table 1 was that the correct value used for the compressibility of water should have been 4.3E-6/m rather than the 9.8E-7/m given here. The CRC Handbook of Chemistry and Physics gives a value of approximately 4.57E-10 per N/m2 at 25 C and atmospheric pressure. Dividing this value by the product of (density)(gravity constant) i.e. (1000 kg/m3) (9.8 m/s2), we obtain approximately the above value per meter of head. In all transient analyses, fluid compressibility affects the storage coefficient which is a key parameter especially in saturated, confined calculations. However, in these unsaturated, unconfined analyses, the storage coefficient is directly related to the porosity and the questionable compressibility value is probably irrelevant since the saturations are much less than unity. Nevertheless, it should be corrected for the sake of consistency with other documents.

All other data values in Table 1 look reasonable.

Treatment of Uncertainty

The two cases described in this memo are very similar to each other and are therefore not capable of addressing the sensitivity of the travel time to uncertainty in the thermal effects of the repository.

Appropriate Use in SCP Section 8.4

The analysis described in this memo is summarized in Section 8.4.3.2.1.2, Item 5. The summary ends with the conclusion that particles released during the first 90 years near the repository have a travel time of 300,000 years with, and 400,000 years without the thermal effects. This conclusion is easily explained by Figures 14 and/or 15 where particles which deviate the most from 1.0 are of greatest concern. Since we are concerned with repository releases, we focus on the top of the column. Clearly, the greatest thermal impacts are felt on particles released during the first 90 years. Nevertheless, the minimum travel time to the water table is seen to be above 75% of the 400,000-year isothermal value. Note that the Figures indicate alarming deviations from 1.0 near the water table. However, [signature] 1-27-89

radionuclides are released only in the vicinity of the repository, therefore these low values are merely of academic interest.

As pointed out earlier, the data from Table 1 in this report is reproduced in Table 3-26 of the SCP. During this review, our primary focus was Section 8.4, but if appropriate information was not found in this section, we looked for it throughout the SCP. Therefore, although this data is compiled in Section 3, the conclusions drawn in (Section 8 of) the SCP, are based on the use of these specific data values. Different data would undoubtedly result in different conclusions.

The discussions in SCP Section 8.4 are an accurate summary of the significant conclusions drawn in the subject report.

General Comments

The top of the review copy was missing (pages 135 through 138).

Noronha 1-27-89

TECHNICAL ASSESSMENT REVIEW SAND88-2784 #4
PART I - ELEMENT 4

Reviewer: Clifford J. Noronha Date: 27 January 1989

Document Reviewed: Peters, R.R., 1988. Hydrologic Technical Correspondence in Support of the Site Characterization Plan", SAND88-2784, NNWSI, Sandia National Laboratories, Albuquerque, NM. (SAIC Reference Number: 3934)

MEMORANDUM 4: The Effect of Seismic and Tectonic Activity on Radionuclide Containment at Yucca Mountain, Nevada

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Reasonableness of the Analyses

This memo addresses the possibility where seismic activity may dam an arroyo (dry stream bed) lying above a fault zone. Subsequently, it is hypothesized that a large storm will create a pond that injects a large amount of water into the unsaturated zone.

The conceptual model consists of a vertical, one-dimensional column of hydrogeologic units extending from the water table (0.0 m) up to land surface (530 m). The five hydrogeologic units are shown in Figure 1, where the subscript "w" is for welded and signifies low conductivities. The subscript "n" is for non-welded and signifies high conductivities, unless it is followed by "z" for zeolitized in which case the conductivity is low.

This water-ponding scenario is simulated using the mathematical formulation embodied in the TOSPAC code. The initial height of water in the pond is assumed to be 10 m, which is stated to be a "reasonable upper limit". This 10 m slug of water is superimposed on the natural, downward, vertical flux of 0.1 mm/yr. The results in Figure 2 indicate that the water flux at the proposed repository level in TSw2-3 (about 240 m above the water table) is expected to only double about 10,000 years after the injection. The authors conclude that injection of a 10 m slug does not have a significant impact on the travel time to the water table. A 15 m head of water would be required to merely initiate flow in the fractures of unit TSw. However, calculations indicate that it would take a 20 m slug of water to saturate the entire column from the surface down to the water table and thus maintain fracture flow.

I believe that the analyses carried out are appropriate and that the approach used is reasonable.

Horanko 1-27-89

Reasonableness of Data

The independent parameters used in these calculations are:

- thicknesses of each hydrogeologic unit
- percolation flux (q),
- matrix (ne) and fracture (nf) porosities
- saturated matrix hydraulic conductivity (Ks)

The Reference Information Base (Version 3.0) contains no hydrologic data. Most of the raw data used in this memo are summarized and compiled in Table 1. The table is divided into matrix and fracture properties. Within each section, various parameter values are given for the five different stratigraphic units being considered in this report.

I found that these values had been reproduced in Table 3-26 of the SCP. However, the Kmb value for CHnz of 2E-11 m/s (1.73E-6 m/d) was a little below the range given in Table 3-27 of the SCP. Another source of these data was found to be Table 6-18 of the Yucca Mountain EA. Porosity values compared reasonably well between various references. Because of its significance to flow calculations, I focused my attention on the hydraulic conductivity values, Kmb.

Notes to Table 1

(b) Kmb = Km (1-nf) = Km (nf <<< 1)
(g) Kfb = Kfnf

A discrepancy noted at the end of Table 1 was that the correct value used for the compressibility of water should have been 4.3E-6/m rather than the 9.8E-7/m given here. The CRC Handbook of Chemistry and Physics gives a value of approximately 4.57E-10 per N/m2 at 25 C and atmospheric pressure. Dividing this value by the product of (density)(gravity constant) i.e. (1000 kg/m3) (9.8 m/s2), we obtain approximately the above value per meter of head. In all transient analyses, fluid compressibility affects the storage coefficient which is a key parameter especially in saturated, confined calculations. However, in these unsaturated, unconfined analyses, the storage coefficient is directly related to the porosity and the questionable compressibility value is probably irrelevant since the saturations are much less than unity. Nevertheless, it should be corrected for the sake of consistency with other documents.

All other data values in Table 1 look reasonable.

Treatment of Uncertainty

The analysis described in this memo is purely deterministic. There was no intent to address uncertainty.

Appropriate Use in SCP Section 8.4

Hlorochs 1-27-89

The analysis described in this memo is summarized in Section 8.4.3.2.1.1, Item 2. The fault was simulated as a highly transmissive zone by increasing the prevailing saturated hydraulic conductivity by a factor of 10,000. The conductivities of the surface units were high enough to permit the slug to infiltrate the TCw and most of the PTn unit in 2.2 days. The SCP infers that the ground-water flux doubles between 10,000 and 100,000 years. According to Figures 2 and 4 in the subject memo, this doubling actually occurs at 10,000 years. Both the SCP and this memo agree that the system returns to the initial conditions after about 200,000 years. Furthermore, both documents conclude that a large, short-duration perturbation such as the one described here, would be attenuated before it reached the repository horizon and would thus have a negligible effect on ground-water travel times and radionuclide transport.

As pointed out earlier, the data from Table 1 in this report is reproduced in Table 3-26 of the SCP. During this review, our primary focus was Section 8.4, but if appropriate information was not found in this section, we looked for it throughout the SCP. Therefore, although this data is compiled in Section 3, the conclusions drawn in (Section 8 of) the SCP, are based on the use of these specific data values. Different data would undoubtedly result in different conclusions.

With the above exception, the discussions in SCP Section 8.4 are an accurate summary of the significant conclusions drawn in the subject report.

General Comment

A global search should be performed on the word "affect". This is the correct spelling of the verb form. However, in this memo, the word occurs most frequently as a noun in which case it should be changed to "effect".

Noronha 1-27-89

TECHNICAL ASSESSMENT REVIEW SAND88-2784 #5
PART I - ELEMENT 4

Reviewer: Clifford J. Noronha Date: 27 January 1989

Document Reviewed: Peters, R.R., 1988. Hydrologic Technical Correspondence in Support of the Site Characterization Plan", SAND88-2784, NNWSI, Sandia National Laboratories, Albuquerque, NM. (SAIC Reference Number: 3934)

MEMORANDUM 5: NNWSI Hydrologic Analysis Number 72-26

A 1-D Calculation Investigating Water-Table Fluctuation at Yucca Mountain

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Reasonableness of the Analyses

This memo attempts to evaluate the time required for the unsaturated zone at Yucca Mountain to drain back to its initial steady-state condition following a temporary rise in the level of the water table.

The conceptual model consists of a vertical, one-dimensional column of hydrogeologic units extending from the water table (0.0 m) up to land surface (530 m). The five hydrogeologic units are shown in Figure 1, where, in the abbreviated, unit-naming convention, the subscript "w" is for welded and signifies low conductivities. The subscript "n" is for non-welded and signifies high conductivities, unless it is followed by "z" for zeolitized in which case the conductivity is low.

Two separate cases were simulated using the mathematical formulation embodied in the TOSPAC code.

Case 1: Initial water table rises to the top of the geologic unit proposed to contain the repository (TSw1-TSw2 interface in Figure 1), and

Case 2: Initial water table rises to the land surface

In both cases, the water table rise is superimposed on an initial condition corresponding to a natural downward flux of 0.1 mm/yr. Case 2 corresponds to a 40% higher initial water-table than Case 1. The drain-back time, however, is 200,000 yr compared to 50,000 years for Case 1. This disproportionate increase in the time for Case 2 is probably due to the high storage effects of the PTn unit.

I believe that the analyses carried out are appropriate and that the approach used is reasonable.

Horache 1-27-89

Reasonableness of Data

The Reference Information Base (Version 3.0) contains no hydrologic data. Most of the raw data used in this memo are summarized and compiled in Tabl 1. The table is divided into matrix and fracture properties. Within each section, various parameter values are given for the five different stratigraphic units being considered in this report. TSw3, CHnv, and PPw are not used. These data correspond to the drill hole USW G-4.

I found that some of these values had been reproduced in Table 3-26 of the SCP. However, the Kmb value for CHnz of 2E-11 m/s (1.73E-6 m/d) was a little below the range given in Table 3-27 of the SCP. Another source of these data was found to be Table 6-18 of the Yucca Mountain EA. Porosity values compared reasonably well between various references. Because of its significance to flow calculations, I focused my attention on the hydraulic conductivity values, Kmb. While TSw and CHnz were within the same order of magnitude between the EA and the subject report, the CHnv value of 2.7E-7 m/s in Table 1 was almost two orders of magnitude higher than the 107 mm/yr (3.4E-9 m/s) reported in the EA.

All other data in Table 1 appear to be reasonable and appropriate.

Treatment of Uncertainty

The cases described in this memo represent the two extremes assuming that the repository unit (TSw2) becomes saturated during the rise in the water table. Case 1 provides a minimum and Case 2 provides an approximate upper limit on the relaxation time. The factor of 4 increase in the drain-back time resulting from only a 40% increase in the water table rise in Case 2 over Case 1, indicates that the results are highly sensitive to the extent of this perturbation.

Appropriate Use in SCP Section 8.4

The analysis described in this memo is summarized in Section 8.4.3.2.1.2, Item 7. The SCP concludes "At 10,000 years, the flux throughout most of the column was at least a factor of 10 more than the steady-state flux". This statement is presumably based on Figures 13(a) and 13(b) in the subject memo. The steady state flux is 0.1 mm/yr or approximately 0.32E-11 m/s. The flux should have been plotted on a log axis to reveal this factor more clearly but at 10,000 years, it looks like a lot less than 10 on Figures 13(a) and 13(b). Also, 200,000 years is <u>sufficient</u> but probably not <u>required</u> to reach steady-state conditions.

As pointed out earlier, the data from Table 1 in this report is reproduced in Table 3-26 of the SCP. During this review, our primary focus was Section 8.4, but if appropriate information was not found in this section, we looked for it throughout the SCP. Therefore, although this data is compiled in Section 3, the conclusions drawn in (Section 8 of) the SCP, are based on the use of these specific data values. Different data would undoubtedly result in different conclusions.

Hhoroska 1-27-89

With the above exceptions, the discussions in SCP Section 8.4 are an accurate summary of the significant conclusions drawn in the subject report.

Editorial Comments

The titles of Figures 14 and 15 should be changed from "early" to "late" times.

Noronha 1-27-89

TECHNICAL ASSESSMENT REVIEW SAND85-0854
PART I - ELEMENT 4

Reviewer: Clifford J. Noronha Date: 27 January 1989

Document Reviewed: Peters, R. R., J. H. Gauthier, and A.L. Dudley, 1986. "The Effect of Percolation Rate on Water-Travel Time in Deep, Partially Saturated Zones", SAND85-0854C, NNWSI, Sandia National Laboratories, Albuquerque, NM. (SAIC Reference Number: 1541)

Reasonableness of the Analyses

The general governing equation described in this report is one for unsteady state, variably-saturated flow in a dual-porosity medium (Equation 1). This equation has various terms describing the storage capacitance due to compressibility of water and dilation of rock. However, the analysis in the report is carried out using only the simplified, steady-state (Equation 7) capability of the code TOSPAC (TOtal System Performance Assessment Code). Therefore, it must be noted that several of the storage-related parameters in Table 1 e.g. compressibilities and coefficients of consolidation show up only in the time derivative and consequently will not play any role in the steady-state analysis done here.

The conceptual model (Figure 7) is a simple, vertical one-dimensional column of stratigraphic units from the water table (0.0 m) up through the repository horizon, TSw (~300 m) to the land surface (530 m). In Figure 7, the subscript "w" is for welded and signifies low conductivities. The subscript "n" is for non-welded and signifies high conductivities, unless it is followed by "z" for zeolitized in which case the conductivity is low.

Three different percolation rates (0.1, 0.5, and 4.0 mm/yr) are applied to the column for each of the two possible sets of properties for the non-welded Calico Hills unit (CHn): v - vitric and z - zeolitized. This is a total of six distinct cases. For each of the six cases, the following output is obtained from the TOSPAC simulations, and plotted vs depth:

	Figures
Pressure head profiles	8 and 9
Relative percolation rate	10 and 11
Matrix Saturation	12 and 13
Water velocity	14, 15, 16, 17

Finally, the travel times in each hydrologic unit are presented in Figures 18 through 23 in the form of three bars; one for the matrix, one for the fractures, and a "minimum" for a combination of the two. From these results, the travel times from the proposed repository location to the water table for each of the six cases are deduced and summarized in Table 3. Five of the six cases yield a travel time of 10,000 yr to 400,000 years which more than adequately satisfies the current 10CFR60 travel time regulation of 1000 years. The sixth case, Hlorasha 1-27-89

involves the highest percolation rate of 4.0 mm/yr, which forces more flow through the fractures rather than the low conductivity, zeolitized Calico Hills (CHn). This predominance of fracture flow reduces the travel time to 3 years. However, the regulations specify the travel time to the "accessible environment" which could involve a prolonged residence time within the saturated zone following the 3 years in the unsaturated zone. I believe that the analyses carried out are appropriate and the approach used is reasonable.

Reasonableness of Data

The Reference Information Base (Version 3.0) contains no hydrologic data. Most of the raw data used in this report is summarized and compiled in Table 1. The table is divided into matrix and fracture properties. Within each section, various parameter values are given for the six different stratigraphic units being considered in this report.

I found that these values had been reproduced in Table 3-26 of the SCP. However, the Kmb value for CHnz of 2E-11 m/s (1.73E-6 m/d) was a little below the range given in Table 3-27 of the SCP. Another source of these data was found to be Table 6-18 of the Yucca Mountain EA. Porosity values compared reasonably well between various references. Because of its significance to even steady-state flow calculations, I focused my attention on the hydraulic conductivity values, Kmb. While TSw and CHnz were within the same order of magnitude between the EA and the subject report, the CHnv value of 2.7E-7 m/s in Table 1 was almost two orders of magnitude higher than the 107 mm/yr (3.4E-9 m/s) reported in the EA.

Notes to Table 1

(b) Kmb = Km (1-nf) = Km (nf <<< 1)
(g) Kfb = Kfnf

A discrepancy noted at the end of Table 1 was that the correct value used for the compressibility of water should have been 4.3E-6/m rather than the 9.8E-7/m given here. The CRC Handbook of Chemistry and Physics gives a value of approximately 4.57E-10 per N/m2 at 25 C and atmospheric pressure. Dividing this value by the product of (density)(gravity constant) i.e. (1000 kg/m3) (9.8 m/s2), we obtain approximately the above value per meter of head. In all transient analyses, fluid compressibility affects the storage coefficient which is a key parameter especially in saturated, confined calculations. However, in these unsaturated, unconfined analyses, the storage coefficient is directly related to the porosity and the questionable compressibility value is probably irrelevant since the saturations are much less than unity. Nevertheless, it should be corrected for the sake of consistency with other documents.

All other data values in Table 1 look reasonable.

[signature] 1-27-89

Treatment of Uncertainty

The authors have addressed uncertainty adequately in their choice of the wide range of parameters. The two compositions of the unit CHn considered, correspond to the extremes that may be found at Yucca Mountain; either it is vitric with a relatively high conductivity (CHnv) or it is zeolitized with a relatively low conductivity (CHnz). In addition, the percolation rates in Table 2 span the range suggested for Yucca Mountain (DOE, 1984). This range also encompasses all flow regimes from predominantly matrix to predominantly fracture.

Use in SCP Section 8.4

As pointed out earlier, the matrix property data from Table 1 in this report is reproduced in Table 3-26 of the SCP. During this review, our primary focus was Section 8.4, but if appropriate information was not found in this section, we looked for it throughout the SCP. Therefore, although this data is compiled in Section 3, the conclusions drawn in (Section 8 of) the SCP, are based on the use of these specific data values. Different data would undoubtedly result in different conclusions.

A reference is made to the subject report in Section 8.4.2.1.6.1, paragraph 2, on page 8.4.2-33. The reference merely states that the CHnz conductivity is comparable to that of TSw and is much lower than that of CHnv. These facts are obvious from Table 1.

The discussions in SCP Section 8.4 are an accurate summary of the significant conclusions drawn in the subject report.

SAND85-0854C

<u>Title</u>: The Effect on Percolation Rate on Water-Travel Time in Deep, Partially Saturated Zones

<u>Authors</u>: R. R. Peters, J. H. Gauthier, and A. L. Dudley

<u>Date of Review</u>: December 21, 1988

<u>Reviewer</u>: Edward M. Kwicklis, U.S. Geological Survey

<u>Data Reasonableness</u>:

The data used in this report is believed to be, in general, reasonable for use in simulating the behavior on the hydrologic system at Yucca Mountain, Nevada.

Matrix properties used in the simulations are those of samples determined by Peters et al. (1984) to be representative of the hydrological units from which they were taken. Peters et al. (1984) chose what they believed to be a representative sample on the basis of (in order of decreasing importance): (1) saturation curve shape; (2) saturated conductivity; (3) porosity and other bulk-properties. The characteristics of matrix samples deemed to be representative of their respective hydrologic units were listed in Table 9 of Peters et al. (1984), and reappeared in essentially unaltered form in Table 1 of SAND85-0854C. On the basis of Table A-4 of Peters et al. (1984), the value of saturated hydraulic conductivity of the representative samples for unit CH_{nv} is 2.7×10^{-7} m/s, rather than the value of 2.7×10^{-9} m/s listed in Table 9 of the sample report.

Because no direct measurements have been made to define the relationship between effective hydraulic conductivity (K) and pressure head (ψ) for any of the hydrogeologic units, this relationship was estimated in SAND85-0854C Report using the method of Mualem (1976), as adopted by Van Genuchten (1978). It has not been demonstrated that these techniques can be applied to either welded or non-welded tuffs. In particular, the expression developed by Mualem (1976) to predict relative conductivity (K_r) as a function of pressure head

$$K_r(\psi) = S_e^{0.5}\left[\int_0^{S_e}\frac{1}{\psi(x)}\,dx \Big/ \int_0^{1}\frac{1}{\psi(x)}\,dx\right]^2$$

(where S_e is effective saturation) is semi-empirical in that the exponent (0.5) of S_e was determined by systematically altering the value of the exponent, and then choosing the value for which the mean deviation (calculated between the measured and predicted values of $K(\psi)$ for 45 soils) was a minimum. It seems desirable to calibrate the value of this exponent for each hydrogeologic unit. This, of course, will require that the relationship between K_r and ψ be determined experimentally for each of these units.

The steady-state distribution of pressure-heads predicted to occur in the SAND85-0854C report for a given recharge rate is expected to be sensitive to the $K(\psi)$ relationships assumed for the hydrogeologic units, regardless of whether flow occurs predominantly in the fractures or in the matrix. Therefore, considerable uncertainty exists regarding the absolute value of pressure head at a given location, although qualitatively, the relative magnitudes of pressure head and pressure-head gradients within and between the units may be reasonable.

One of the fundamental conclusions of the report is that travel times through each of the units will be extremely long when the flux is predominantly through the matrix. This conclusion will remain unchanged regardless of assumptions made about $K(\psi)$ for the matrix. In addition, because the $K(\psi)$ and $S_e(\psi)$ relationships assumed for the fractures allow no fracture flow to be initiated until the matrix in the welled tuffs are completely saturated, the $K(\psi)$ relationship assumed for the matrix in these units should not alter the circumstances under which fracture flow occurs.

I found the data and the assumptions regarding the fracture network properties to be reasonable, with the exception of the $K(\psi)$ and $S_e(\psi)$ relationships assumed for the fractures. I think there is considerable inconsistency in assuming the same Van Genuchten coefficients can be used to describe the hydraulic behavior of fractures having equivalent hydraulic apertures of 27.0 and 4.5 microns. Clearly, the different transmissive properties of the fractures indicate that each has a different aperture distribution than the other, and therefore they should drain and become non-conductive over different ranges on pressure head. And once, again, one can expect that the spatial distribution of pressure heads will be sensitive to the assumptions regarding $K(\psi)$ for the fractures in the welded units, when the recharge rate results in significant fracture flow. However, travel times would not be expected to be particularly sensitive to the $K(\psi)$ and $S(\psi)$ relationships assumed for the fractures, given the method of analysis used. Most of the sensitivity would result from differences in $S(\psi)$, which is used to compute flow velocity in the fractures (equation 9).

Reasonableness of Analysis Method

I believe that when the average pore-water velocity for water in the fracture is calculated as the fluid flux in the fracture, divided by the effective saturation of the fracture, and the travel time across a unit is calculated using this velocity, a drastic underestimation of travel time for this 'average' water particle can result. This approach does not allow for an exchange of water molecules between the fracture and matrix pore-domains, a process that would be observed if a tracer experiment was run in which tritium-tagged water was used. A composite porosity model such as the one used in this study needs to define a more gradual relationship between 'effective porosity' - that portion of the total water-filled pore spaces available to store tracer moving through the fracture system - and the flux of water moving through the fractures. Intuitively, one would expect this effective porosity to be much less than the total porosity at high fracture fluxes, and approach the total porosity as the fracture flux becomes negligible. The effective porosity gradually becomes larger because diffusive exchange between fractures and matrix becomes more important at smaller fracture fluxes. The use of only matrix moisture content or fracture moisture content to computer fluid velocities results in an unrealistically abrupt decrease in travel times with only a slight increase in recharge; one would intuitively expect travel times to decrease in a much more gradual manner.

Also, even for a given recjarge rate and stratigraphic configuration, one would expect that there would be a distribution of arrival times at the water table, depending on the particular path each water molecule has traversed. 'Travel-time' should not be calculated on the basis of a first arrival, or on the performance of the 'average' water particle, but should somehow be tied to regulatory criteria which specify the maximum allowable mass loadings of a conservative tracer to the water table by a specified elapsed time.

Statement on Treatment of Uncertainty

By varying the net recharge rate at the land surface, as well as the composition and hydraulic properties of the Calico Hills unit, the authors of SAND85-0854C have indicated that they clearly appreciate the need for a systematic analysis of the uncertainty in the model parameters. However, in this report, no attempt was made to investigate to what extent changes in assumed hydraulic parameters, for units other than the Calico Hills, might affect the results obtained in this study. This reviewer feels that the $K(\psi)$ relationships assumed in the present study clearly dictate the distribution of pressure heads and gradients at steady-state. However, the basic conclusions drawn in this study will remain unchanged, for reasonable changes to the system parameters, given the model assumptions and the method of analysis used. As discussed earlier, the method of analysis, rather than the data itself, probably contributes far more uncertainty about the validity of the results.

Statement of Appropriateness of the use of the Analysis

Only one reference to SAND85-0854C could be located in Section 8.4 of the SCP. The report was cited in connection with the fact that the zeolitized portion of the Calico Hills unit had a saturated matrix permeability comparable to the overlying Topopah Springs welded unit, but that the vitric facies of the Calico Hills had a saturated matrix permeability several orders of magnitude greater than the Topopah Springs. While this statement is not incorrect, perhaps a more basic data report could have more appropriately been used to substantiate this observation.

References

Mualem, Y., 1976. "A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Materials," Water Resources Research 12(3):513-522.

Peters, R. R., E. A. Klavetter, I. J. Hall, S. C. Blair, P. R. Heller, G. W. Gee, 1984. "Fracture and Matrix Hydrologic Characteristics of Tuffaceous Materials from Yucca Mountain, Nye County, Nevada, SAND84-1471, Sandia National Laboratories, Albuquerque, New Mexico.

Van Genuchten, R. 1978. "Calculating the Unsaturated Hydraulic Conductivity with a New Closed Form Analytical Model," Water Resources Bulletin, Princeton University Press, Princeton University, Princeton, New Jersey.

Edward M. Kwicklis 1-23-89

review of:

Peterson, Eaton, Russo, and Lewin: "Technical Correspondence in Support of an evaluation of the Hydrologic Effects of Exploratory Shaft Facility Construction at Yucca Mountain." SAND88-2936 (SAIC Reference No 3935)

by: Keith Kersch Keith Kersch 22-Dec-1988

This report is a collection of four letter reports written by various authors at Sandia. Reports B and C contain data in the form of DATA Statements in FORTRAN subroutines. Included are the subroutines to calculate water distributions in the geologic units of: Calico Hills, Topopah Springs, Paintbrush Tuff, and Tiva Canyon. The same subroutines are used in both reports, with slight modifications for each of the geologic units. The subroutines were designed to calculate properties for the different units depending on the parameter "MAT", which varies in value from 4, for Calico Hills Zeolitic, to 9, for Tiva Canyon. If MAT is passed into the subroutine with a value of 4, it should calculate properties for Calico Hills Zeolitic. It appears that the subroutines were not used this way - instead, the desired properties in the data statement were put in at MAT = 7. Since the entire program and data are not available, it is not clear why this was done. This method does not appear to effect the validity of the calculations.

Porosity values in report A, Table 1 are supposedly taken from the RIB, yet I do not find their values in either version 1, 3, or 4 of the RIB. The values of matrix porosity, however, are close to those reported in the RIB except for the reported value for Calico Hills (they report 46% while values in the RIB range from 29-36%). Since the calculated depth of invasion by construction water is so short there will be no adverse impact on the design by this error.

The fracture porosity, reported in table 1 of report A, is only found in version 2 of the RIB, which was withdrawn. Version 4 of the RIB lists number of fractures per meter in several wells. From these values I calculated the fracture thicknesses that would correspond to the fracture porosities in table 1 and they appear reasonable.

In the second report (report B) on page 31 it erroneously states that the data are included in Figure 1 are taken from the RIB, when figure 1 contains no data. This appears to be a copy of the corresponding page from report A.

The data used are reasonable except that the compressibility of rock in the Paintbrush Tuff appears to be too high by a factor of about 10 in reports B and C. This judgment is based on professional opinion, as I have not seen results measurements of compressibility of any of the rocks. Fracture compressibility appears to be reasonable but I am not qualified to judge this parameter, as I have no experience in this area.

Uncertainty in Report A is addressed by varying the amount of drilling water to be retained by the formation from 1 to 10% (the maximum anticipated amount).

The analysis methods used in these reports appear to be reasonable. It does not appear that repository performance would be adversely affected by choosing less conservative data or analysis methods.

TECHNICAL ASSESSMENT REVIEW

Reviewer: August C. Matthusen August C. Matthusen 1/20/89 Date: January 20, 1989

Reference: Reda, D. C., 1986. "Influence of Transverse Microfractures on the Imbibition of Water Into Initially Dry Tuffaceous Rock" in Proceedings Symposium on Flow and Transport Through Unsaturated Rock, AGU Fall Meeting, San Francisco, Cal., December 1986, SAND86-0420C, Sandia National Laboratories, Albuquerque, N. Mex.

Reasonableness of the data and parameter values:

The cited reference does not represent an analysis done in support of the ESF design nor does it contain any conclusions regarding the suitability of the ESF design or construction. The cited document discusses the results of an empirical study on the flow of water into an unsaturated medium. The SCP does not draw conclusions directly from this information nor use it to support any analyses. The data reported in the SCP are a reasonable discussion of the experimental results reported in the reference. A review of the reference indicates that the laboratory and experimental procedures appear reasonable.

Use of the report to form conclusions in 8.4:

No direct conclusions are formed in Section 8.4 of the SCP based on the information presented in the report. However, a conclusion from the report that the presence of transverse microfractures can slow the propagation of the liquid water wetting front is reported in the SCP and the material in the report is used appropriately as general support of the concept that the movement of water through the unsaturated zone is slow.

20-Jan-1989

To: Augie Matthusen

Joe R Tillerson

From: Joe R. Tillerson

Subject: Transmittal of Consolidated Review of RIB Version 03.001

Attached for your use is the consolidated review of the RIB and the individual reviews on which the consolidation is based. There are four aspects missing from the package. These are:

a. Review sheet by Charlie Voss on in situ stress,
b. Signature by Ed Kwicklis on geothermal gradient review,
c. Signature by Ed Kwicklis on stratigraphy review,and
d. Signatures by Voss, Kimball, and Kwicklis on the consolidated review.

Please contact these reviewers for the material necessary to complete the package. Except for the areas indicated above, all the attachments are originals intended for use in the TARR.

cc

6310 J. E. Steigler
6314 J. R. Tillerson (day file)
6310 60/12462/DIM-231/1.1/Q1
YMP CF

20-Jan-1989, 1

SUMMARY OF REFERENCE INFORMATION BASE REVIEW: VERSION 3.001

Reviewers: Jeff Kimball, Ed Kwicklis, Joe Tillerson, and Charles Voss

Review of: The Nevada Nuclear Waste Storage Investigations Project Reference Information Base, Version 03.001, Issued December 1987.

Review Basis: Individual technical areas of the RIB were identified and review responsibilities were assigned. The individual reviews are documented as attachments to this summary. The reviews were generally based on comparisons of the property values presented in the RIB with values presented in data summary discussions published in heavily reviewed documents such as the EA and the SCP, on the reviewers knowledge of site data and on comparisons of the parameter values with measured data for either tuff (Yucca Mountain or G-tunnel) or other similar rocks. The reviewers were aware that a detailed evaluation of the reference properties to be proposed for use in Title II design was being conducted. The document review here was not intended to duplicate or eliminate the pre-Title II activities. This review, therefore, focused on whether or not the values for parameters available in the RIB Version 03.001 were reasonable for use in ESF Title I design.

RIB History:

The original draft version 01.001 of the RIB was issued as an example of a proposed structure and format for the RIB in April 1986 for review comment by Project participants. In May 1987, draft version 02.001 was released as Sandia National Laboratories Letter Report SLTR87-6001. The information in the second draft, which incorporated review comments received on the original draft information, was updated and modified. The content was considerably expanded by incorporating a select fraction of the information compiled in the course of producing the NNWSI Site Characterization Plan Conceptual Design Report (SCP-CDR). In August 1987, a replacement page set was released for updating the RIB content from draft version 02.001 to draft version 02.002. This replacement page set provided an example of the mechanism proposed for regularly updating the content of the evolving information base.

Version 03.001 is the base version of the RIB used in the ESF Title I design and was released for Project use in December 1987. The content of this version includes only those items from version 02.002, which were identified as required for use in Title I Exploratory Shaft Facility (ESF) design.

Review Comments:

The following areas contained within the RIB were considered during this review of the RIB:

1.3.1.1	Stratigraphy
1.3.1.2	Rock physical properties
1.3.1.2	Rock thermal properties
1.3.1.4	Rock mechanical properties
1.3.1.6	In situ stresses
1.3.1.7	Geothermal gradient

1.7.1.2	Design earthquake
1.1.1	Meteorology data
1.16	Soil and excavated tuff properties
2.2.8	Ramps and Shafts
2.4.3	Extreme wind loads

Not all of the areas were evaluated during the review. The review comments and the reasons for eliminating some of the areas from the review are documented below:

Stratigraphy -

The RIB shows both geologic stratigraphy and a "thermal/mechanical" or functional type of stratigraphy. References were provided in the RIB to trace the development of the stratigraphy. Conclusions were drawn in the review that the correlation between thermal/mechanical and geologic stratigraphy appears to be reasonable and consistent with information in the supporting reference. Clarification of the source of unit thicknesses used in one of the figures was requested.

Rock Physical Properties -

Comparisons of several of the numbers in the table of physical properties with SCP Tables 2-14 and 2-16, EA Table 6-13 and data from other reports, indicates reasonable values have been used in the RIB for the porosity and density.

Rock Thermal Properties

Comparisons of the thermal conductivity values in the RIB (1.3.1.3, p. 2 of 5) with Table 2-14 of the SCP, Table 2-11 of the SCP, thermal conductivity values in Table 6-40 of the EA, and data from other reports indicate that the RIB values are reasonable. As regards thermal expansion, values (1.3.1.3, P 4 of 5) comparisons with SCP Table 2-13 and Table 6-40 of the EA indicate reasonable values for the thermal exp. coefficient; it is noted that the RIB values for the TsW2 unit are generally lower than the value used in the EA.

Rock Mechanical Properties

Based on comparisons with values used in EA evaluations, data presented in some of the reports published on data from Yucca Mountain, and data presented in the SCP, it is concluded that the values for the reference intact rock properties are reasonable. It is pointed out that in several cases there are relatively wide variations in some of the measured values of the data and that careful control of test conditions are warranted to help lessen the variability in the data. As regards the rock mass properties, the RIB values appear reasonable but, especially for horizons in which field tests will not be conducted, it may be necessary have sensitivity evaluations completed to analyze thermal and thermomechanical effects over a relatively wide range of property values.

Data and observations planned during ES construction and testing should provide significant insight into the variability of the properties and should aid in reducing the uncertainties in the Tables, particularly as related to the TsW2 unit.

Comparisons of property values from the G-tunnel Grouse Canyon member with the properties of the Topopah Spring tuff at Yucca Mountain indicate (SCP Table 2-16) that many of the properties related to thermal and thermomechanical response are similar. This indicates that it would be reasonable to use analyses of G-tunnel openings and results of experiments to simulate similar phenomena at Yucca Mountain in the repository horizon.

In Situ Stresses -

Based on previous reviews of in situ ambient stress reports and analyses of Yucca Mountain topography effects, the values for in situ stresses are considered reasonable.

Geothermal Gradient -

The values for the geothermal gradients listed in the RIB are considered to be reasonable for use in the ESF Title I design. 1The reviewer noted that a more recent evaluation of geothermal gradient data is available and should be considered in future RIB updates.

Design Earthquake -

Relative to the design of the ESF, it was indicated that the seismic design value quoted in the RIB is consistent with values quoted in the SCP and SCP/CDR. The reviewer also indicated an awareness of more detailed, ongoing evaluations related to providing criteria for Title II design. It was concluded that the value of 0.4 g peak horizontal acceleration is appropriate and reasonable based on preliminary analyses discussed in Appendices F and L of the SCP/CDR regarding which structures, systems and components are important to safety.

Meteorology -

Meteorology information was not evaluated as part of this review since it is not primary information related to the subjects of this technical assessment review. The values are being evaluated by others as part of the preparation of the RIB version to be used during Title II design.

Soil and Excavated Tuff Properties -

This information was not evaluated in the review since it is not primary site information related to the subjects of this technical assessment review. The values are being evaluated by others as part of the preparation of the RIB version to be used during Title II design.

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Information on Ramps and Shafts -

This information was not evaluated in this review since the ESF repository interface drawings (R07048A in the SDRD) are used to control this interface.

Extreme Wind Loads

This information was not evaluated in the review since it is not primary site information related to the subjects of this technical assessment review. The values are being evaluated by others as part of the preparation of the RIB version to be used during Title II design.

Conclusions and Recommendations: It was concluded by the reviewers that the RIB values available for the Title I design of the ESF were, in general, reasonable for use in simulating the behavior of the ESF at Yucca Mountain. While the RIB version 03.001 indicates that a process has been established to maintain and control the flow of interpreted technical information within the project, it is recognized as needing substantial expansion prior to its use in Title II design of the ESF. The reviewers were not tasked with identifying the information needed in the RIB for Title II design but feel very strongly that perhaps the most critical need is for the hydrologic information known about the site to be interpreted and reference values established appropriate for ESF design and design analyses.

Concurrence:

Name	Signature	Date
Jeffrey K. Kimball		
Ed Kwicklis		
Joe R. Tillerson	Joe R Tillerson	1-20-89
Charles Voss		

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Conclusions and Recommendations: It was concluded by the reviewers that the RIB values available for the Title I design of the ESF were, in general, reasonable for use in simulating the behavior of the ESF at Yucca Mountain. While the RIB version 03.001 indicates that a process has been established to maintain and control the flow of interpreted technical information within the project, it is recognized as needing substantial expansion prior to its use in Title II design of the ESF. The reviewers were not tasked with identifying the information needed in the RIB for Title II design but feel very strongly that perhaps the most critical need is for the hydrologic information known about the site to be interpreted and reference values established appropriate for ESF design and design analyses.

Concurrence:

Name	Signature	Date
Jeffrey K. Kimball		
Ed Kwicklis	Edmund M. Kwicklis	1-23-89
Joe R. Tillerson	Joe R Tillerson	1-20-89
Charles Voss		

20-Jan-1989, 4

Information on Ramps and Shafts -

This information was not eva'''ate n this r iew since the ESF repository interface draw.ngs (R07048A in the SDRD) are used to control this interface.

Extreme Wind 'oads

Thi. inf'::mation was not evaluated in the review since it is not prim.. ·-ite information related to the subjects of this technical assessment review. The values are being evaluated by others as part of the preparation of the RIB version to be used during Title II design.

Conclusions and Recommendations: It was concluded by the reviewers that the RIB values available for the Title I design of the ESF were, in general, reasonable for use in simulating the behavior of the ESF at Yucca Mountain. While the RIB version 03.001 indicates that a process has been established to maintain and control the flow of interpreted technical information within the project, it is recognized as needing substantial expansion prior to its use in Title II design of the ESF. The reviewers were not tasked with identifying the information needed in the RIB for Title II design but feel very strongly that perhaps the most critical need is for the hydrologic information known about the site to be interpreted and reference values established appropriate for ESF design and design analyses.

Concurrence:

Name	Signature	Date
Jeffrey K. Kimball	Jeffrey K Kimball	1-24-89
Ed Kwicklis		
Joe R. Tillerson	Joe R Tillerson	1-20-89
Charles Voss		

20-Jan-1989, 4

Information on Ramps and Shafts -

> This information was not evaluated in this review since the ESF repository interface drawings (R07048A in the SDRD) are used to control this interface.

Extreme Wind Loads

> This information was not evaluated in the review since it is not primary site information related to the subjects of this technical assessment review. The values are being evaluated by others as part of the preparation of the RIB version to be used during Title II design.

Conclusions and Recommendations: It was concluded by the reviewers that the RIB values available for the Title I design of the ESF were, in general, reasonable for use in simulating the behavior of the ESF at Yucca Mountain. While the RIB version 03.001 indicates that a process has been established to maintain and control the flow of interpreted technical information within the project, it is recognized as needing substantial expansion prior to its use in Title II design of the ESF. The reviewers were not tasked with identifying the information needed in the RIB for Title II design but feel very strongly that perhaps the most critical need is for the hydrologic information known about the site to be interpreted and reference values established appropriate for ESF design and design analyses.

Concurrence:

Name	Signature	Date
Jeffrey K. Kimball		
Ed Kwicklis		
Joe R. Tillerson	Joe R Tillerson	1-20-89
Charles Voss	Charles Voss	1/23/89 ~~1-23-89~~

19-Jan-1989

Joe R Tillerson

Reviewer: Joe R. Tillerson

Review of: Nevada Nuclear Waste Storage Investigations Project Reference Information Base, Version 03.001, December, 1987
Section 1.3.1.2 - Rock Physical Properties
Section 1.3.1.3 - Rock Thermal Properties
Section 1.3.1.4 - Mechanical Properties - Intact Rock
Section 1.3.1.6.1 - In Situ Stress

This memo documents my review of various sections of the RIB prepared for use in Title I design as regards reasonableness of the values. The review was conducted on between December 14, 1988 and January 19, 1989. My review is based upon (1) comparison of the RIB values for various rock characteristics with values that were identified in chapter 2 of the SCP that summarizes the data that have been measured on cores obtained from Yucca Mountain, (2) comparison of the RIB values with values that were identified in various sections of the EA, (3) comparison of RIB values of selected properties, particularly for the TsW2 unit, with measured values of the same parameters reported in two data reports, (4) my knowledge of various measurements made on rocks taken from Yucca Mountain or on samples taken from G-Tunnel, (5) my familiarity with data from experiments conducted in G-Tunnel, and (6) my familiarity with analysis results related to in situ stress conditions at Yucca Mountain. I chose to use the SCP and EA documents to support my evaluations because these documents provide summaries of the data obtained on the Yucca Mountain tuffs, both documents been extensively reviewed by numerous technical people with a wide variety of backgrounds, and I am not aware of any general comments that have been made to indicate that there are major concerns with the data sections of these documents.

For all of the parameters or properties that I evaluated, I concluded that the values in the RIB (version 3.0) are reasonable for use in the ESF Title I design. My comments related to the parameters in specific sections of the RIB are:

Section 1.3.1.2 - Rock Physical Properties

I compared the several of the property values in the table (sec. 1.3.1.2, page 2 of 2) with values in SCP Tables 2-14 and 2-16, Table 6-13 from the EA, and with TsW2 data from SAND 85-0762. These comparisons indicated that reasonable values have been used in the RIB for the porosity and density.

Section 1.3.1.3 - Rock Thermal Properties

I compared the thermal conductivity values in the RIB (sec. 1.3.1.3, page 2 of 5) with similar parameters in SCP Table 2-14, SCP Table 2-11, Table 6-40 of the EA, and with data from SAND88-0624. I concluded that in all cases the RIB values are reasonable.

I compared the values for the coefficient of thermal expansion in the RIB (sec. 1.3.1.3, page 4 of 5) with similar parameters in SCP Table 2-13, EA Table 6-40, and with values for TsW2 presented in SAND85-0732. These comparisons indicate that the RIB values are reasonable although it is noted that the RIB values for the TsW2 unit in the RIB are generally lower than the value used in the EA.

Section 1.3.1.4.1 - Mechanical Properties-Intact Rock

In this section, I only reviewed the values presented for the modulus of elasticity, Poisson's ratic, unconfined compressive strength, and tensile strengh of the TsW2 unit. I compared these values to data in SAND85-0732 and concluded that the RIB values are reasonable. C. Voss reviewed the entire set of properties in this section. In considering the values for intact properties of all of the units, it is evident that there is relatively wide variation in several of the values. This indicates that it will be desirable to have careful control of test conditions to help lessen the variability in the data taken in future tests. It is expected that tests and observations planned during ES construction and testing should provide significant insight into the variability of the properties and should aid in reducing the uncertainties in the values of the parameters, particularly as related to the TsW2 unit. However, considering the number of samples that have been tested to date, it is reasonable to expect that significant variability may exist even after site characterization is completed. This implies that it will be necessary to have sensitivity evaluations completed to analyze thermal and thermomechanical effects over a relatively wide range of property values.

I also compared property values from the G-tunnel Grouse Canyon member with the properties of the Topopah Spring tuff at Yucca Mountain. This comparison (see SCP Table 2-16) indicates that many of the properties related to the thermal and thermomechanical response of these two formations are similar. This indicates that it would be reasonable to use analyses of G-tunnel openings and results of experiments to simulate similar phenomena at Yucca Mountain in the repository horizon.

19-Jan-1989

Section 1.3.1.6.1 - In Situ Stress

Based on previous reviews of calculations related to topography effects on in situ stresses, I consider that the values and ranges for the in situ stresses documented in the RIB (sec. 1.3.1.6.1, page 2 of 2) are reasonable.

References:

1. Nimick, F. B., and B. M. Schwartz, 1987, "Bulk, Thermal, and Mechanical Properties of the Topopah Spring Member of the Paintbrush Tuff, Yucca Mountain, Nevada," SAND85-0762, Sandia National Laboratories, Albuquerque, NM.

2. Nimick, F. B., 1988, "Thermal-Conductivity Data for Tuffs from the Unsaturated Zone at Yucca Mountain, Nevada," SAND88-0624, Sandia National Laboratories, Albuquerque, NM.

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Telephone (202) 479-0500

Date: January 23, 1989

To: Joseph Tillerson

From: Charles Voss

Subject: Review of the YMPO Reference Information Base (RIB)

The in situ stress data in Version 3.001 of the RIB (December 1987) was reviewed on January 9, 1989 to assess the reasonableness of the data. My assessment of the RIB data is based on a review of related discussions in Section 2.6 of the Site Characterization Plan and the references provided below. Based on these reviews, the limited number of measurements made, and the inherent uncertainty associated with stress measurements, the large range of principal stress magnitudes and orientations provided in the RIB are considered to be reasonable.

Charles F. Voss

Charles V
Signature

Date 1/23/89

References:

Stock, J.M, J.H. Healy, S.H. Hickman, and M.D. Zoback, 1985. "Hydraulic Fracturing Stress Measurements at Yucca Mountain, Nevada, and Relationship to the Regional Stress Field," Journal of Geophysical Research, Vol. 90, No. B10, pp. 8691-8706.

Ellis, W.L. and J.E. Magner, 1980. Compilation of Results of Three-Dimensional Stress Determinations Made in Rainier and Aqueduct Mesas, Nevada Test Site, Nevada, USGS-OFR-80-1098, Open-File Report, U.S. Geological Survey, Denver, Co.

Bauer, S.J., J.F. Holland, and D.K. Parrish, 1985. "Implications About In Situ Stress at Yucca Mountain," Proceedings of the Symposium on Rock Mechanics, Vol II, Rapid City, N. Dakota.

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Date: January 16, 1989

To: Joseph Tillerson

From: Charles Voss

Subject: Review of the YMPO Reference Information Base (RIB)

The thermal/mechanical stratigraphy in Version 3.001 of the RIB (December 1987) was reviewed on January 9, 1989. The objective of the review was to assess the reasonableness of the stratigraphic units identified as having similar thermal/mechanical properties. The basis for the RIB data is the three-dimensional property model described in Ortiz et al., 1985 and the process used to interpolate property values between measurement points. My assessment of the RIB data, therefore, is based in part on my review of this process and a comparison between the RIB values and the values presented in Ortiz et al. Based on this assessment, the thermal/mechanical stratigraphy provided in Version 3.001 of the RIB is considered to be reasonable.

Charles F. Voss

Charles Voss
Signature

Date 1/16/89

Ortiz, T. S., R. L. Williams, F. B. Nimick, B. C. Whittet, and D. L. South, 1985. A Three Dimensional Model of Reference Thermal/Mechanical and Hydrologic Stratigraphy at Yucca Mountain, Souther Nevada, SAND84-1076, Sandia National Laboratory, Albuquerque, NM.

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Date: January 16, 1989

To: Joseph Tillerson

From: Charles Voss

Subject: Review of the YMPO Reference Information Base (RIB)

The intact and rock mass mechanical properties in Version 3.001 of the RIB (December 1987) were reviewed on January 9, 1989. The objective of the review was to assess the reasonableness of the mechanical properties of the various tuff units. The bases for the assessment were: (1) a comparison of the RIB property values with those in the Chapter 2 of the DOE Site Characterization Plan; (2) comparison of the RIB property values with other rock types; and (3) my participation in the review and preparation of Chapter 2 of the SCP and the laboratory and field data upon which the values are based. Based on my assessment, the intact and rock mass mechanical properties provided in Version 3.001 of the RIB are considered to be reasonable.

Charles F. Voss

Charles Voss
Signature

Date 1/16/89

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Reviewer: Jeffrey K. Kimball   Date: January 18, 1989

Document Reviewed: Reference Information Base, Version 3.001, Issued December, 1987, specifically the seismic design values quoted.

Reasonableness and Appropriateness of the Seismic Design Value: The seismic design value quoted in the RIB is consistent with values quoted in the SCP and the SCP/CDR; this value is 0.4g peak horizontal acceleration. This value is reasonable and appropriate based on the preliminary analysis discussed in Appendices F and L of the SCP/CDR regarding which structures, systems, and components are important to safety (summarized in section 6.1.4 of the SCP). Based on these preliminary results no ESF structures, systems, and components were identified as being important to preclosure safety. Thus, any seismic design only needs to meet DOE requirements, such as those found in DOE Order 6430 (General Design Criteria). 0.4g is conservative when compared to the DOE Order. As input to future design efforts (Title II), a working group has recommended that the seismic design value for the ESF liner be based on a peak ground acceleration of 0.3g; this value should be used in future versions of the RIB. This value is more consistent with DOE Order 6430 than the use of 0.4g, and is considered conservative as long as future evaluations continue to show that ESF structures, systems, and components are not important to preclosure radiological safety as defined by 10 CFR Part 60.

Jeffrey K Kimball 1/18/89

Signature   Date

TECHNICAL ASSESSMENT REVIEW

Reviewer: August C. Matthusen August C. Matthusen 1/20/89 Date: January 20, 1989

Reference: Ross, B., 1987. A Survey of Disruption Scenarios for a High-Level-Waste Repository at Yucca Mountain, Nevada; SAND85-7117 Sandia National Laboratories, Albuquerque, N. Mex.

Review: While it was suggested that Ross (1987) may contain conclusions or analyses important to the Title I design of the ESF, the reference does not discuss the ESF to any great degree and mainly describes scenarios for postclosure disruption of the repository. These scenarios do not include the affects of the ESF on the repository or on repository performance (with the possible exception of the discussion of shaft seal failure on pages 42 and 43). The scenarios in Ross do not address the potential affects of the ESF on waste isolation, the potential for test interference, or the potential for representativeness of the ESF. Additionally, Ross (1987) is not cited in Section 8.4 of the SCP where the supporting analyses for ESF design are discussed. Ross (1987) is cited extensively in Section 8.3.5.13 (Total System Performance) with regard to postclosure repository performance.

The SCP does contain a significant discussion of scenarios which evaluate potential affects of the ESF on repository performance in Section 8.4.3.3.1.2. The scenarios in this section that discuss potential effects of ESF construction on the repository are not identical to those discussed in Section 8.3.5.13 or Ross (1987) for postclosure repository performance. The scenarios in 8.4 represent a new subset of potential repository disruption scenarios based on the potential affects of the ESF on repository waste isolation, the potential for test interference, and the representativeness of the data. The scenarios evaluated are based upon the same sets of nominal and disruptive initiating processes and events as the scenarios for postclosure performance discussed in Section 8.3.5.13 of the SCP and in Ross (1987). In view of this, the evaluation of scenarios for ESF affects on repository performance as used in Section 8.4 appears reasonable and appropriate.

11-Jan-1989

Joe R. Tillerson

Joe R. Tillerson

Review of: St. John, C.M., 1987, Interaction of Nuclear Waste Panels with Shafts and Access Ramps for a Potential Repository at Yucca Mountain, SAND84-7213, Sandia National Laboratories, Albuquerque, NM, (SAIC Ref. No. 2704)

Data Reasonableness

1. Data are not in exact agreement with the RIB (version 3.0) but are sufficiently close to be judged reasonable values to be used in simulations of the behavior of Yucca Mountain.

The author very clearly identifies the parameters used in the evaluation and provides a table that compares the data used with the RIB values that existed at the time the report was published. Since that time, version 3.0 of the RIB was developed. In general, the values used in the report are reasonable when compared with the ranges indicated in the RIB (3.0).

Reasonableness of Analysis Methods

1. The analysis methods used in these estimates of the thermal stresses that would exist at shafts or ramps in the repository at Yucca Mountain are reasonable and appropriate.

The author clearly identifies the analysis methods used for the calculations. In general, linear elastic methods are applied. The computer codes (HEFF, STRES3D, and SHAFT) are identified and references are given to where more information on the codes can be found. While I recognize that it is possible to use other, more sophisticated analysis methods to simulate the behavior of tuff, I also believe that elastic evaluations are appropriate considering the behavior of the tuff in lab and field tests, the stress conditions predicted by the analyses, and the widespread use of such techniques in geomechanics evaluations of opening stability.

Treatment of Uncertainty

1. The analyses were not intended evidently to be a complete sensitivity evaluation of factors influencing stresses in shafts and ramps but the author clearly recognized some of the major uncertainties regarding the results of the analyses and adequately treated them in the report. These areas of treatment included evaluating different in situ stress states, evaluating the applicability of 2-D versus 3-D analyses, and evaluating different potential modes of deformation or failure that might be applicable to the Yucca Mountain site.

The impact of different values for the in situ stresses (horizontal) was assessed. The potential for the development of new fractures was analyzed and the potential for slip along existing fractures was also evaluated. The effect that the location of the shaft has on stresses to be experienced by a liner was evaluated by considering two different locations (in a pillar within the repository and at the edge of the repository). The author clearly recognized many of the limitations of the analysis methods (e.g. properly variations with depth were not included and that uncertainties exist with regard to how to interpret the effects of slip along existing joints). The author also indicated that, consistent with the approach being taken in the Yucca Mountain project, thermally-induced stresses should be considered in the design of the shafts because of the possibility of creating thermally-induced cracks in the liner. The thermally-induced stresses on arched ramps were considered in the assessments of the different displacement/deformation modes.

Appropriateness of Analysis use in ESF Title I Design Evaluations

1. I believe that the analyses have been appropriately used in the design evaluations in SCP section 8.4 except for one incorrect reference made to the document that should have been to a different document by the same author.

The evaluations are appropriately summarized in a discussion of thermal effects on stability. The summary correctly indicates that the rock mass surrounding the shaft was not expected to be fractured because of the in situ or thermally induced loading and that cracks in the liner could be produced but that there was no evidence that such cracking would be detrimental to the performance (stability) of the liner or the performance of the site. The document is appropriately referenced as one of several analyses that provide a basis for estimating the extent of the stress changes that occur near drifts and alcoves as a result of excavation. The discussion in the SCP concluded that a 2-diameter standoff distance is sufficient to account for the stress-altered zone around the opening considering that the analyses generally show that stresses are within 10 percent of the initial in situ stresses beyond one drift diameter. This is also one of the documents that can be considered to support the standoff between the ESF and the repository.

In section 8.4.3.2.3.1, the report is incorrectly referenced in item 9, page 8.4.3-29. The reference citation should be to a different document by the same author. The correct reference citation should be to St. John (1987c), ie to SAND86-7005.

Recommendations: If an errata sheet for the SCP is prepared, the incorrect reference (see above) to St. John (1987a) should be corrected to read St. John (1987c).

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Charles Voss 1/28/89

Reviewer: Charles F. Voss   Date: January 20, 1989

Document Reviewed: St. John, C., 1987. "Investigative Study of the Underground Excavations for a Nuclear Waste Repository in Tuff," SAND83-7451, Sandia National Laboratories, Albuquerque, NM.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (Version 3.0)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 3.0 Reference Information Base

Version 3.0 of the RIB was reviewed as part of the TAR and an assessment was made of the reasonableness of the data. The review was performed by several TAR members based on their technical area of expertise and familiarity with properties of the Yucca Mountain site. Comments concerning the reasonableness of the RIB values are contained in the review of the RIB included in Appendix I.

2. Appropriateness of the data and parameters used in the analyses

The objectives of the analyses in this report were to evaluate the effects of rock bolts and excavation-induced damage on the behavior of the rock mass around typical drifts and to evaluate the influence of opening shape, dimensions, and the in situ stress state on the rock mass response. The analyses were initiated prior to the time baseline project data was established in 1986 and were based on the available data. Two different sets of material property data were used for the rock bolt/excavation-effects analyses and the opening shape/stress state analyses. Differences exist between the rock bolt/excavation-effects data and Version 3.0 of the RIB, specifically the modulus and Poisson's ratio. The opening shape/stress state analyses were performed at a later time and the first version of the engineering data base for rock mass properties was near completion. The data used is consistent with Version 3.0 of the RIB.

The data used in the opening shape/stress state analyses is considered appropriate based on the comparison made with Version 3.0 of the RIB and my understanding of the laboratory measurements made on tuff. Some of the data used in the rock bolt/excavation-effects analyses is considered inappropriate given the current understanding of rock mass properties (the analyses used the most recent information available for estimating the material properties at the time the analyses were performed). However, based on my reading of 8.4 (see item 5) the use of the results of these analyses to reach conclusions concerning the possible impacts of site characterization on performance objectives appears to be very limited. Furthermore, because the objective of the analyses was to compare the response of the rock mass to various design considerations (i.e., rock bolt support and different opening shapes and stress states) the variation in material properties noted above would not change the conclusions of the report. While the variations would effect the predicted response, all the calculations would be effected simularly.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

The analyses used both the finite element and the boundary element methods for modeling the behavior of the rock mass around emplacement drifts. The assumption that the rock mass behaves as a homogeneous, linear elastic medium was made for all the analyses. The two-dimensional models assume the vertical stress is a principal stress and represent the rock mass response for drifts remote from intersections oriented perpendicular to a horizontal principal stress direction. The isotropic stress state assumed for the rock bolt/excavation-effects analyses is significantly higher than the RIB value because at the time the analyses were performed the repository was assumed to be at a lower depth with equal stresses. The opening shape analyses considered three horizontal-to-vertical stress ratios (0.0, 0.5 and 1.0) with a vertical stress equal to the overburden pressure at the proposed repository depth (approximately 300 m).

A Mohr-Coulomb failure criterion was assumed for the rock mass in all of the analyses. A vertical joint set with a strike parallel to the axis of the drifts was included in the opening shape analyses. A linear Coulomb-Navier failure criterion was assumed.

The conceptual models and analytical methods that were used are considered appropriate based on: (1) the stated objectives of the analyses; (2) the information and data available at the time the analyese were performed; and (3) the apparent limited use of the results of the analyses for reaching conclusions concerning potential impacts of site characterization activities on performance objectives.

4. Consideration of data uncertainty

The analyses did not consider data uncertainty. Single values were used.

5. Use of the analyses to form conclusions in 8.4

Section 8.4.3, page 8.4.3-29 contains a brief summary of the analyses contained in the document. Based on the text in section 8.4, the results of the analyses do not appear to influence the conclusions reached concerning possible impacts of site characterization activities on performance objectives.

Conclusions:

The rock bolt/excavation-effects analyses material property data, although appropriate at the time the analyses were performed, are considered inappropriate at this time based on the values in Version 3.0 in the RIB. However, the use of the conclusions reached from the analyses in this report in Section 8.4 considerations is minimal. Therefore, in my opinion, no action or changes are required. The data and conceptual models used in the opening shape/stress state analyses is considered appropriate although the results appear to have little import in the performance considerations in section 8.4.

Recommendations:

None.

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Charles Voss 1/23/89

Reviewer: Charles F. Voss Date: January 20, 1989

Document Reviewed: St. John, C., 1987. "Reference Thermal and Thermal/Mechanical Analyses of Drifts for Vertical and Horizontal Emplacement of Nuclear Waste in a Repository in Tuff," SAND86-7005, Sandia National Laboratories, Albuquerque, NM.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (Version 3.0)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 3.0 Reference Information Base

Version 3.0 of the RIB was reviewed as part of the TAR and an assessment was made of the reasonableness of the data. The review was performed by several TAR members based on their technical area of expertise and familiarity with properties of the Yucca Mountain site. Comments concerning the reasonableness of the RIB values are contained in the review of the RIB included in Appendix I.

2. Appropriateness of the data and parameters used in the analyses

The objective of the analyses was to provide comparative predictions of anticipated conditions in and around emplacement drifts for vertical and horizontal emplacement configurations. Data used in the analyses was from several sources: (1) the 1986 version of the RIB (where available); (2) relevant sources; or (3) engineering judgment. Average properties of the welded, lithophysae-poor, devitrified Topopah Spring tuff were used for the matrix and rock mass values. The major deviation from Version 3.0 of the RIB is the unconfined compressive strength value of the rock matrix which is approximately one-half the magnitude of the value given in the RIB (a conservative assumption). Based on the comparison with Version 3.0 of the RIB and my understanding of the laboratory measurements made on tuff from the proposed repository site the data used in the analyses is considered reasonable.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

The analyses use both finite element and boundary element methods to evaluate the conditions around both ventilated and unventilated emplacement rooms. The models of the emplacement drifts are represented as two-dimensional structures with the surrounding rock assumed to behave as a homogeneous, linear elastic material. Furthermore, the material properties are assumed not to change with time or temperature over the ranges considered in the analyses. The vertical stress was assumed to be equal to the overburden pressure and the mean horizontal-to-vertical stress ratio was used. The failure criteria employed to evaluate potential instability around the emplacement rooms were a linear Coulomb criterion for the rock matrix and a Coulomb-Navier criterion for the joints. Based on the stated objectives of the report and the current understanding of the site conditions the models and methods used are considered appropriate.

4. Consideration of data uncertainty

No attempt was made in the analyses to consider the uncertainty associated with the data or the conceptual model. Only average values were used.

5. Use of the analyses to form conclusions in 8.4

Section 8.4.3, page 8.4.3-29 contains a brief summary of the results from the analyses. Based on the text, the results of the analyses do not appear to play a significant role in reaching any conclusions concerning site characterization affects on performance. The reference given appears to be incorrect. The reference should be "St. John (1987c)".

Conclusions:

The data used in the analyses is considered reasonable based on the stated objective of the study. Furthermore, the conceptual models and the analytical methods are thought to be appropriate given the current level of understanding of the site. It appears that the results of the analyses were not used extensively to support the analyses of the potential impacts of site characterization activities on performance objectives.

Recommendations:

Correct reference provided on page 8.4.3-29, item 9.

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Charles F. V 1/23/89

Reviewer: Charles F. Voss Date: January 20, 1989

Document Reviewed: St. John, C., 1987. "Thermomechanical Analysis of Underground Excavations in the Vicinity of a Nuclear Waste Isolation Panel," SAND84-7208, Sandia National Laboratories, Albuquerque, NM.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (Version 3.0)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 3.0 Reference Information Base

Version 3.0 of the RIB was reviewed as part of the TAR and an assessment was made of the reasonableness of the data. The review was performed by several TAR members based on their technical area of expertise and familiarity with properties of the Yucca Mountain site. Comments concerning the reasonableness of the RIB values are contained in the review of the RIB included in Appendix I.

2. Appropriateness of the data and parameters used in the analyses

The objective of the analyses was evaluate the temperature and stresses around access drifts, emplacement drifts, and the intersection of the two drifts. Vertical and horizontal emplacement configurations were considered but emphasis was given to the latter. The analyses were initiated prior to the time baseline project data was established in 1986 and the data used was based on available data sources.

The material properties used in the analyses are, except for the joint properties, intact or matrix values. The elastic modulus used is approximately 75% greater than the rock mass value in Version 3.0 of the RIB. As a result, the thermomechanical stresses are much greater than would result if the rock mass value was substituted in the analyses. The unconfined compressive strength used in the failure criterion for the rock matrix was 10% higher than the rock mass unconfined compressive strength. Overall, the results of the analyses are likely to be conservative compared to the results if RIB values were used. In addition, the results from the analyses appears to play little or no role in the assessment of possible impacts from site characterization activities on performance objectives (see item 5). Therefore, in my opinion, the data are considered appropriate as used in the analyses.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

A combination of finite element, boundary element, and closed-form analytical methods were used to perform one-, two-, and three-dimensional analyses. A hydrostatic stress state was assumed. The overburden pressure (vertical stress) is based on a repository at a depth of 366 m below the surface so the stress is somewhat higher than for the proposed repository depth. Failure of the rock matrix and the assumed vertical joints were estimated based on Mohr-Coulomb and Coulomb failure criterion respectively.

These analytical methods and conceptual models are considered appropriate given the stated objective of the analyses and the limited use of the results in the assessment of potential impacts of site characterization on performance objectives.

4. Consideration of data uncertainty

The analyses did not consider data uncertainty; single values were used.

5. Use of the analyses to form conclusions in 8.4

Section 8.4.3, page 8.4.3-29 contains a brief summary of the analyses contained in the document. The results of the analyses do not appear to influence the conclusions reached concerning possible impacts of site characterization activities on the performance objectives. The reference given appears to be incorrect. The reference should be "St. John (1987d)".

<u>Conclusions:</u>

Some of the material property data used in the analyses is inconsistent with the values contained in Version 3.0 of the RIB. Based on my review of the report, it appears these inconsistencies result in more conservative estimates of the extent of disturbance around the simulated drifts. The analytical methods used are considered appropriate given the current understanding of the site. The use of the results of the analyses in 8.4 appear to be very limited.

Recommendations:

The reference provided on page 8.4.3-29, item 8 should be corrected.

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Charles F. Voss 1/23/89

Reviewer: Charles F. Voss   Date: January 20, 1989

Document Reviewed: St. John, C. and S. Mitchell, 1987. "Investigation of Excavation Stability in a Finite Repository," SAND86-7011, Sandia National Laboratories, Albuquerque, NM.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (Version 3.0)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 3.0 Reference Information Base

Version 3.0 of the RIB was reviewed as part of the TAR and an assessment was made of the reasonableness of the data. The review was performed by several TAR members based on their technical area of expertise and familiarity with properties of the Yucca Mountain site. Comments concerning the reasonableness of the RIB values are contained in the review of the RIB included in Appendix I.

2. Appropriateness of the data and parameters used in the analyses

The objective of the analyses in the report was to determine whether the location of the access drifts relative to the emplacement panels is an important design consideration for a repository in tuff. The material properties used are consistent with the values in Version 3.0 of the RIB and are considered appropriate as used in the analyses.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

The conceptual model used is comprised of four panels within which waste canisters are emplaced in long horizontal holes. The analyses consider a vertical cross section, perpendicular to the emplacement holes, passing through the panels. No surface topographic features were considered (i.e., uniform vertical stress) and the rock mass was assumed to behave as a homogeneous, linear elastic material. The repository dimensions used are in general consistent with the SCP/CDR. Thermomechanical analyses were performed using the boundary element code HEFF. Results were postprocessed to determine whether the stresses were sufficient to fail the rock matrix or generate slip along existing fractures having several different orientations. A Mohr-Coulomb failure criterion was assumed for the rock matrix and a Coulomb criterion for the joints. Two stress field were assumed. The vertical stress in both was assumed to be equal to the overburden stress. Horizontal-to-vertical stress ratios of 0.25 and 1.1 were used.

Based on the stated objectives of the analyses and the current understanding of the site conditions the models and methods used are considered appropriate.

4. Consideration of data uncertainty

In general, average values were used for the material properties in the analyses with no consideration being given to the variability of these properties at the site. The stress states considered represent bounding values based on the current hypotheses. This limited treatment of data uncertainty is considered appropriate given the objective of the analyses, i.e., to assess the significance of drift location on repository design considerations.

5. Use of the analyses to form conclusions in 8.4

Section 8.4.3, page 8.4.3-30 briefly mentions this report and provides a short summary of the results. I could find no other mention of the report in section 8.4.

<u>Conclusions:</u>

The data, conceptual models, and methods used in the analyses are considered appropriate based on the stated objectives and my understanding of the site conditions. Based on my reading of Section 8.4 of the SCP, it does not appear that the results of these analyses were used extensively to form opinions concerning possible impacts of site characterization activities on performance objectives. It is interesting to note, however, a conclusion reached in the report that is not mentioned in Section 8.4 that appears to be relevant to the consideration of possible impacts the site characterization activities may have on performance. The authors note that the joint activation around the access drifts due to both excavation induced and thermomechanical stresses is very sensitive to joint orientation. Large regions of joint activation are possible for shallow dipping joints (and the assumed failure criteria and joint properties). The dislocation of joints can conceivably alter the hydrologic properties of the rock mass.

The large difference in the volumes of rock being heated in these analyses and that proposed in the ESF thermomechanical investigations make it difficult to assess the significance of this conclusion relative to possible impacts of site characterization activities on performance objectives without performing additional analyses. The analyses by Bauer et. al. (1988) indicate the temperature and stress changes around the canister scale heater test after 30 months of heating extends only 15 m radially from the heater. For the heated room experiment, the thermally induced stresses fall off to in situ values at approximately 30 m. Unfortunately, the analyses do not consider whether failure of the rock mass (joint activation) might occur. The logic used in Section 8.4 was to assume no changes would occur outside the extent of the thermal or stress gradients introduced by the experiment. This appears to be consistent with the reasoning in the NRC Generic Technical Position for estimating the extent of the disturbed zone. It would be interesting and useful, however, to postprocess the results of the Bauer et. al. analyses using the failure criteria contained in the St. John and Mitchell report to assess the extent of joint activation for different joint orientations.

Recommendations:

Consider postprocessing the results of Bauer et. al. (1988) analyses using a Coulomb criteria to estimate the extent of joint activation for subhorizontal joints.

References:

Bauer, S., L. Costin, and J. Holland, 1988. "Preliminary Analyses in Support of In Situ Thermomechanical Investigations," SAND88-2785, Sandia National Laboratories, Albuquerque, NM.

TECHNICAL ASSESSMENT REVIEW

PART I - ELEMENT 4

Charles F. Voss 1/23/89

Reviewer: Charles F. Voss Date: January 20, 1989

Document Reviewed: Technical Letter Memorandum RSI(ALO)-0037, "Estimates of Expected Values and Ranges of Temperature, Stress, and Strain Along the Exploratory Shaft at the Yucca Mountain Project." Appendix B.3, Vol. 4B, ESF Title I Design Summary Report.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objectives of this review are to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The evaluation considers the following:

1. the reasonableness of the data in the RIB (Version 3.0)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

1. Reasonableness of the parameter values in Version 3.0 Reference Information Base

Version 3.0 of the RIB was reviewed as part of the TAR and an assessment was made of the reasonableness of the data. The review was performed by several TAR members based on their technical area of expertise and familiarity with properties of the Yucca Mountain site. Comments concerning the reasonableness of the RIB values are contained in the review of the RIB included in Appendix I.

2. Appropriateness of the data and parameters used in the analyses

The objective of the study was to provide estimates of the expected values and expected variations of temperature, stress, and strain in the vicinity of ES-1 during the first 100 years of repository operation. The analyses considered a range of values for the independent variables expressed as a mean value and a percent variation about the mean. The ranges of parameter values are considered reasonable based on the fact that they were generally taken from the version of the RIB used in the conceptual design of the repository (See SAND84-2641). The thermal and mechanical properties do not differ significantly from the values used in the Title I design.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

The conceptual model is inadequately described in the document for the purpose of assessing its appropriateness. The technical letter memorandum simply reports results that were extracted from a document referenced as "in preparation" (Brandshaug). The Brandshaug model is a two-dimensional linear elastic representation of a tuff repository. The initial temperatures and stresses used in the model are consistent with Version 3.0 of the RIB.

4. Consideration of data uncertainty

The expected value and expected deviation of the dependent variables (i.e., stress, strain, and temperature) in the vicinity of the ESF were calculated based on the range of values considered for the independent variables. Bounding values were used to represent the extreme variation of each independent variable

5. Use of the analyses to form conclusions in 8.4

The analyses are not referenced in Section 8.4.

Conclusions:

The analyses to not appear to have been used to evaluate the potential impact of the ESF on the performance of the site. Furthermore, it is unclear to what extent (if any) this report was used in the Title I design. Because of the three-dimensional effects that influence the rock mass surrounding the exploratory shafts, the use of this two-dimensional analysis is considered most appropriate as either a very preliminary analysis or for benchmarking three-dimensional models.

Recommendations:

The objectives of the report and use of information contained in it should be clarified if the report will be used to support the Title II design.

Review of:

Wang & Narasimhan: "Hydrologic Modeling of Vertical and Lateral Movement of Partially Saturated Fluid Flow Near a Fault Zone at Yucca Mountain," August 1988, SAND87-7070

By: Keith M. Kersch Keith M Kersch 25-Jan-1989

This report is not directly referenced in the SCP, but the work has bearing on the analyses and could have been referenced. The conclusions presented here do not contradict the conclusions of other authors. Wang & Narasimhan conclude that there is not much diversion of water caused by tilting. The main thrust of this work is in comparing the results of different model configurations, which is probably why it has not been included as a reference in the SCP. The SCP says that there will be studies directed to determining if there is any lateral diversion. Some parts of the SCP where this work might have been referenced are attached. This review has produced no recommendations.

The data used are reasonable and similar to data used by other researchers, some of which is reported in the RIB. The saturated conductivity values reported in the RIB are lower than values used by earlier researchers.

The calculational approach is reasonable and is consistent with the accuracy of the data available.

Uncertainty in the data is not really addressed, since this was more of a conceptual study than a study to determine the absolute magnitude of some hydrologic property of Yucca Mountain.

Review of:

Water, Waste & Land, Inc., 1986: "Analyses of Observed Flow Between Test Wells USW G-1 and USW UZ-1", NRC Mini Report 6 (SIAC Reference No 3861)

By: Keith M. Kersch KMKersch 23-Jan-1989

This report contains very little data. It contains scoping calculations to help explain the presence of drilling water in USW UZ-1 that was lost during the drilling of USW G-1. The impact of this report in the design of exploratory shaft is to mention that dry drilling will be used where possible to prevent such occurrences in the future. The only citation in 8.4 of the new SCP is in 8.4.3.2.1.2, item 12: Ground water flow in matrix and fractures. Since the scoping calculations are not used in the design, it is not necessary to judge the adequacy of the data used. The data values and the approach used, however, are reasonable for the scoping calculations.

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TECHNICAL ASSESSMENT REVIEW COMMENT RECORD

TECHNICAL ASSESSMENT REVIEW SUBJECT: ESF TITLE-1-DESIGN ACCEPTABILITY ANALYSIS, PART I-ELEMENT 4: ASSESSMENT OF APPROPRIATENESS OF DATA USED AND TREATMENT OF UNCERTAINTY

REVIEWER(S) Ralph Cady ORGANIZATION DOE/HQ

TOPIC Water-vapor Flow in an Open Borehole (SCP p. 8.4.3-19)

REFERENCE Weeks, E.P., 1987. "Effects of Topography on Gas Flow in Unsaturated Fractured Rock: Concepts and Observations," American Geophysical Union Geophysical Monograph 42, D.D. Evans and T.J. Nicholson (eds.), pp. 165-170

COMMENTS This reference is used by the SCP because it reports observations of air and water-vapor flow in two wells on Yucca Mountain. The reference also provides scoping calculations of topographic and barometric effects that may explain summer observations but are not sufficient to explain ~~RECOMMENDATIONS~~ winter observations. The citation and use of Weeks (1987) in the SCP is appropriate based on my review of both documents.

RECOMMENDATIONS: None

Ralph Cady
1/23/89

DATE REVIEW COMPLETED 1/2/89 SIGNATURE Ralph Cady

2-1370

Review of:

Weeks: "Effect of Topography on Gas Flow in Unsaturated Fractured Rock: Concepts and Observations."

By: Keith M. Kersch Keith M Kersch 16-Jan-1989

This report contains a minimum of calculations in support of some experimental observations of barometric and topographic effects on air flow from and into open boreholes. The results of the calculations are NOT used in the design of the ESF. Section 8.4 of the SCP only refers to Weeks' observation that there is air flow into and out of the wells at the top of Yucca Mountain. Weeks' calculations show that the air flow is larger than would be expected by using his mathematical model. The only reference of consequence in the SCP is on page 8.4.3-19, where it states that topographically induced air flow may result in drying of the rock in the vicinity of the well. This is a valid conclusion that demonstrates that water movement rates will be higher if this effect is not included. Another consequence is that the rate of movement of air in rocks is probably higher than was previously thought.

The data and mathematical model used by Weeks were reasonable. Uncertainty is not addressed in his calculations, but the calculations have no impact on the design. More work is need in this area to determine the impact of this work on performance assessment.

TECHNICAL ASSESSMENT REVIEW COMMENT RECORD

Sheet 1 of 6

TECHNICAL ASSESSMENT REVIEW SUBJECT: ESF TITLE-1-DESIGN ACCEPTABILITY ANALYSIS, PART I-ELEMENT 4: ASSESSMENT OF APPROPRIATENESS OF DATA USED AND TREATMENT OF UNCERTAINTY

REVIEWER(S) Ralph Cady ORGANIZATION DOE/HQ

TOPIC Effect of water used during exploratory shaft construction. (SCP p 8.4.3-18)

REFERENCE West, K.A., 1988. Exploratory shaft Facility Fluids and Materials Evaluation, LA-11398-MS, Los Alamos National Laboratory, Los Alamos, N.M.

COMMENTS The SCP relies on West (1988) for three estimates; the percentage of water introduced in the subsurface that is not recovered and the estimates of water that will be used during construction of the shafts and drifts. (see attached)

RECOMMENDATIONS none

DATE REVIEW COMPLETED 1/4/1989 SIGNATURE Ralph Cady

 Ralph Ca[dy]

West (1988) solicited expert opinions on the amount of drilling fluid that could reasonably be removed during shaft and drift construction (see p. 131 of West, 1988). A conservative bound on the estimates offered is ten percent.

In the second ¶ of p. 131 of West (1988), "3018 L per m of advance is given as an estimate of the water used under normal shaft sinking conditions. This estimate was provided to West by Fenix & Scisson. The estimate given in the SCP is "3.08 m³ of water per meter of shaft depth"; essentially the same amount.

The SCP further states that West (1988) estimates 165 m³ of water per meter of drift length. I am unable to find such an amount given in WEST (1988).

NOT HAVING EXPERIENCE IN CONSTRUCTION METHODS PLANNED FOR USE IN THE ESF, I AM UNABLE TO JUSTIFY ESTIMATES PROVIDED TO WEST (1988) AND EXTRACTED FOR USE IN THE SCP.

Ralph Cady
1/23/1989

TECHNICAL ASSESSMENT REVIEW
Reviewer: Paul L. Cloke
Field: Geochemistry

PART I - ELEMENT 4

Reference: West, K. A., 1988. "Nevada Nuclear Waste Storage Investigations Exploratory Shaft Facility Fluids and Materials Evaluation", LA-11398-MS, Los Alamos National Laboratory, Los Alamos, NM.

Summary of the Data Review Process Used in TAR Part I - Element 4

The objective of this review is to evaluate the adequacy of the relevant analyses and calculations used in ESF Title I design and the performance assessments related to NRC concerns 1, 2, and 3. The overall evaluation process considers the following:

1. the reasonableness of the data in the RIB (Version 03.001)

2. the appropriateness of the data and parameters used in the analyses

3. the appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used

4. how data uncertainty was considered in the analyses and adequacy of the considerations with regard to the three NRC concerns

5. the use of the analyses to form conclusions in Section 8.4 of the SCP concerning whether the ESF design and construction satisfy the three general objectives in 10 CFR Part 60.

This portion of the overall review of this reference considers only items 1 through 4, above, and is restricted to geochemical data and concerns. To a large extent the geochemistry has been rolled up into hydrology in the ESF Title I design, and, therefore, hydrogeochemical concerns are also included.

1. Reasonableness of the parameter values in Version 03.001 Reference Information Base

This version of the RIB contains no geochemical data, and only one set of data, on annual precipitation, relevant to the hydrogeochemical concerns addressed in this review. The average annual precipitation at Yucca Flat was used by the reviewer together with an estimated area of the Yucca Mountain site, obtained by approximate measurement of the area of the outline shown in SCP/CD, Overview, Figure 3-2, to calculate a reasonable expected gallonage of precipitation expected on the site. This calculation yielded about 390 million gallons/yr., in reasonable agreement with the value of 230 million gal/yr. cited in SCP section 8.4.3.2.1.3, in view of the differences in elevation and geographic position.

2. Appropriateness of the data and parameters used in the analyses

A. Cited Data

Many of the data cited relate to hydrology or engineering practice. These include the amount of water to be used during construction, amounts of materials used, percentage of water recovered, etc. Whereas the amounts and compositions of all these materials and fluids are relevant to impacts on geochemistry, their evaluation in respect to appropriateness and accuracy has been delegated to other reviewers.

The following data from West (1989) were used in respect to geochemistry in SCP sections 8.4.2 and 8.4.3:

a. Water use during construction and testing associated with the ESF, 33.2 million gallons. The accuracy of this value was not evaluated in this portion of the overall review.

b. Penetration of blasting (chemical) by-products during construction into drift and shaft walls, 1 to 1.5 m. These are primarily gases, such as NO, CO, NH_2, and CH_4, but include some solids, such as Al_2O_3. The penetration is based upon opinion only with no supporting documentation of measurements in actual mining practice or calculations. On the basis of this reviewer's experience in underground mines this depth of penetration seems reasonable, as judged from visual impressions of crack propagation caused by blasting. However, actual measurements of penetration should be made prior to the start of in situ testing to assure that no significant impact on geochemistry has occurred at depths into the rock at which the tests are to be performed.

c. Penetration of water during construction into the drift and shaft walls, <10 m. Evaluation of this value is primarily hydrological and was left for a different reviewer. However, on the basis of this reviewer's experience in underground mines this depth of penetration seems reasonable, as judged from visual impressions of crack propagation caused by blasting and water seepage in unfractured fresh granite. Actual measurements of penetration should be made prior to the start of in situ testing to assure that no significant impact on geochemistry has occurred at depths into the rock at which the tests are to be performed.

d. Percentage of construction water not recovered, 10%. This is a mining engineering issue not addressed by this reviewer. Appendix B of the report assesses the opinion of several mining engineers.

e. Water use during shaft sinking, 3.02 m^3 water/m shaft depth. This is a mining engineering issue not addressed by this reviewer. Value cited from F&S.

f. Water use during drift advance, 1.65 m^3 water/m drift length. This is a mining engineering issue not addressed by this reviewer. Value cited from F&S.

g. Percentage of water retained in rock matrix around shaft, 10%. This is a hydrological issue not addressed by this reviewer.

h. Separation of ESF shafts, drifts, and alcoves from waste containers, ≥30 m. This is a design issue not addressed by this reviewer. On the assumption that this separation is sufficient to be beyond any significant opening of fractures as a consequence of stress relief during mining and in view of the maximum estimated penetrations of introduced fluids of about 10 m, this is reasonable from a geochemical point of view.

i. Materials or pairs of materials used during construction of the ESF that will have a significant impact, none. This is interpreted to mean that any materials identified would already be known to have a significant impact. The conclusion was reached by means of a decision tree. Whereas this reviewer has some reservations about this tree as discussed in section 3 of this review, the conclusion appears to be correct in respect to the interpretation given above.

j. Materials used during construction of the ESF that could have a potentially significant impact, 2 categories—hydrocarbons and solvents. This conclusion was also reached by means of decision trees about which this reviewer has some reservations discussed in the next section. Nevertheless, it is agreed that one or more materials in these categories of materials are the most likely to produce significant impacts.

k. Penetration of hydrocarbons used underground into the rock, a few cm. The basis for this assessment is not apparent. Actual measurements of penetration should be made prior to the start of in situ testing to assure that no significant impact on geochemistry has occurred at depths into the rock at which the tests are to be performed. It seems unlikely that hydrocarbons will penetrate more deeply than does water. Thus the maximum penetration is probably <10 m, which is still acceptable.

l. Penetration of solvents used underground into the rock, ≤ a few cm. The basis for this assessment is not apparent. Actual measurements of penetration should be made prior to the start of in situ testing to assure that no significant impact on geochemistry has occurred at depths into the rock at which the tests are to be performed. It seems unlikely that hydrocarbons will penetrate more deeply than does water. Thus the maximum penetration is probably <10 m, which is still acceptable.

m. Depth penetration of water insoluble organic compounds used at ESF surface, probably similar to water penetration, i.e., ca. 10 m. This assessment seems reasonable.

n. Amount of organic compounds lost at ESF surface, negligible. The text indicates that this means negligible compared to the average annual precipitation, which was assessed using apparently resonable estimates. The real question is whether the amount is negligible with respect to impacts on the repository. To address this question one needs to evaluate how much of the spill, or loss, reaches the repository, and how effective these compounds may be in changing ground water chemistry and complexing and transporting radionuclides. Specifically, the important point is not whether the concentration of a complexant is small, say 1 ppm, but whether it can complex about the same mass of a highly radioactive radionuclide, say 1 ppm. An increase of 1 ppm of some radionuclides would be highly significant. However, on the basis of the rationale used for data items l and m, above, it is agreed that the amount of organic compounds lost at the ESF surface that reaches the repository horizon is probably negligible.

o. Hydrocarbons and solvents expected to produce a significant impact on the repository, none. This seems likely to be the most controversial conclusion of West (1988). This decision was reached by consideration of the amounts, recovery, travel time from the places used to the waste packages, reactivity, and reaction rate (if any) of the various materials. Many, if not all, of these data are approximated or qualitative rather than quantitative. The conclusion, therefore, is open to question. No data are provided in the report on the reactivity, reaction rate, or catalysts required to permit significant reaction, even though it is stated that all of these were considered. It is presumed, therefore, that the the panel of experts made judgmental decisions in respect to these factors. In reassessing this conclusion this reviewer relied only on travel time and direction. It is agreed that travel time from the surface for hydrocarbons and solvents is unlikely to be less than that for water, i.e. >10,000 yrs. Travel direction from the underground workings is expected to be primarily downward, away from the waste emplacement area, a point not made in West (1988). In the short term, specifically during construction and testing in the ESF, it is agreed that hydrocarbon and solvent transport, as well as that of other constituents, will be comparable to, or less than, that of drilling fluid. Thus, horizontal transport toward emplacement drifts is expected to be sufficiently limited in the short term.

For the long term diffusion should, perhaps, be considered. This is not taken into account in West (1988). If tracers can move 10 cm in granite under a moderate pressure gradient in 3 months, as cited by Birgersson and Neretnieks (1982, cited in SCP Section 8.4.2.3.6.1) for granite, it is not obvious to this reviewer that significant amounts of organic compounds cannot in 1000 years diffuse the 30 m from the ESF to the nearest waste package. This tends to imply that an evaluation is needed during site characterization and that a change in the repository layout may be required so that the nearest emplacement drift is more than 30 m from the ESF. On the other hand introduction of hydrocarbons into the repository itself during its excavation will surely be comparable to that into the ESF, making such an analysis irrelevant. Instead this shifts the emphasis to an analysis to show whether the presence of hydrocarbons near waste packages will produce a significant impact. I.e. it seems likely that any compromising of the isolation capability of the site from ESF activities will be less than the unavoidable compromising during repository construction.

p. Biodegradation, conclusions drawn:

i. All organic compounds to be used are biodegradable.

ii. Inorganic compounds to be used are mostly not biodegradable, or biodegradability is not known.

iii. The organic compounds could support a large population of microorganisms.

iv. Degradation of many organic compounds is expected to be slow.

v. Microorganisms can exist in Yucca Mountain, but there are no known problem areas nor identified detrimental consequences. Impact will probably depend on fluid transport.

vi. The quantities of organic compounds and the rock properties will limit the impact of biodegradation.

This reviewer believes that the conclusions are reasonable in the short term. The long term case is analogous to that in the previous item. One may, therefore, conclude that the activities in the ESF in respect to this and the previous item will have no significant effect on repository performance because the introduction of organic materials and microorganisms directly into the repository during its construction will greatly surpass any effect arising from the ESF.

q. Volumes of fluids other than water used during construction of the ES, much less than the volume of water. This was estimated semi-quantitatively and seems very reasonable.

r. Quantities of gases produced from explosives (NO, CO, NH_2, CH_4), small. Presumably this means in comparison to air. Thus, it is reasonable that most of the gases will promptly be removed by the ventilation. They must be for safe operation.

s. Quantities of solids produced from explosives (Al_2O_3), small. Compared to the quantity of other solids, i.e. rock, this is clearly true. Much of this will be removed with the muck. It seems reasonable that the impact will be negligible.

t. Change in water saturation in repository 10 m from openings, <0.002. This is a hydrological issue not evaluated by this reviewer.

B. <u>Materials and Substances Not Considered</u>

In spite of the apparent intent for the report by West (1988) to be comprehensive the following were not discussed: a) exhaust from the diesel motors, b) combustion products that would result in the event of an underground fire, c) volatile materials resulting from electrical shorts, or overheating or burning of electrical insulation, d) chlorine and/or sodium hypochlorite that are planned to be added to water piped underground, e) wood, f) plastic (Bektaplast) intended to be used as a liner for shaft sumps, and g) leachate from the septic tank leach field, which overlies the controlled area but not the waste emplacement area. It is also possible that, in the event of a fire at the surface facilities at or near the shaft collars, some combustion gases, fine particles, cinders, etc., could enter the shaft. The effects of such a mishap are not expected to be more serious than an underground fire.

Whereas most of the diesel exhaust will be removed through ventilation, some will be deposited as a black carbonaceous coating on exposed rock walls. However, the impact of this is expected by this reviewer to be similar to that of various other organic substances and not to affect the NRC concerns. The various combustion, including those from wood, or overheating products are expected to behave similarly and likewise not to be of concern. The gases produced by any such combustion or heating, which may constitute a considerable quantity, are of more concern than solid or liquid products.

However, the introduction of highly oxidizing water, which would result from water chlorination, should be avoided. Even small quantities of an oxidant would have a pronounced effect on the redox potential (Eh) of the poorly poised groundwater in Yucca Mountain, and the chloride degradation product of the chlorination would, even in low concentrations, have deleterious effects on the performance of many metals. Thus, it is recommended by this reviewer that chlorine be excluded. This parallels a recommendation in West (1988), "Do not use tracers containing chlorine in Well J-13 water during the mining of the ESF..." Finally, the plastics to be used are thought to be sufficiently inert to pose no problem. This reviewer does not wish to express an opinion on the effects of leachate from the septic area, except that it is viewed as a potentially significant problem.

3. Appropriateness of the conceptual models in the analyses and the appropriateness of the analytical method(s) used.

The discussion in this section is restricted to geochemistry and biogeochemistry.

To address the great complexity of the many materials to be used in the ESF and their interactions with each other and the rock, LANL identified a panel of materials scientists and chemists. This panel agreed to several criteria that would provide sufficient reasons for eliminating a material for consideration. The panel then applied these criteria to a list, intended to be comprehensive, of the materials that would be used in the ESF by going through a decision tree to eliminate those of no concern. In a similar fashion pairs of materials were considered. Through this decision process none of these materials or pairs of materials was identified as likely to produce a significant impact on the repository. The reader of West (1988) may surmise that such reasons as 1) the material is used only at the surface and cannot travel to the repository in 10,000 years, or 2) the material will be fully recovered and removed from the site were used to conclude that the material was not of concern at this time. However, for materials identified through the decision trees as of "high concern" the criterion or combination of criteria used to make this final decision in respect to short or long term impacts was not specified individually for each material or pair. Rather such rationale was applied only to the broad categories of hydrocarbons and solvents. This procedure is judged to be adequate, in view of the considerable flexibility to change the repository design on the basis of data obtained during site characterization, to provide reasonable assurance that the construction and operation of the ESF will not compromise the ability to characterize the site and to permit the ESF site characterization activities to provide representative data. These correspond to NRC concerns (2) and (3). It is adjudged that evaluations of these concerns are not very sensitive to considerable uncertainties in the various estimated values, owing to the (geologically) short time frame during which measurements and tests will be made.

It is less certain that the long-term waste isolation capability of the site will not be compromised—NRC concern (1). It is here that long-term extrapolations of uncertain data are most important. Nevertheless, because of the expected dominant downward movement of contaminants, the long term effects of ESF activities should be greatest below the emplacement horizon. In this direction, as contrasted to horizontal movement, a much greater distance exists within which the effects of contaminants may be mitigated by dilution, sorption on mineral surfaces, etc. This means that uncertainties in the data are of much less importance than would otherwise be the case. Thus, in this case also, it is adjudged that with reasonable assurance the capability of the site to provide long-term isolation of the waste is not compromised. However, this should be investigated further during site characterization. Although not documented in the report, it is possible that logic similar to this was followed by the panel inasmuch as travel distances and proximity of various materials to each other were considered.

In some instances materials were considered to be of low or no concern because their concentrations by the time they might reach a waste package were estimated as being low. As noted above, even low concentrations of strong complexing agents may increase radionuclide solubilities to low, but highly significant, concentrations. Thus, this rationale is not considered appropriate. Nevertheless, other considerations apply in these instances with the result that the conclusions of the decision process do not appear to be invalidated.

Biological degradation and transport was carefully and thoroughly considered. The degradation products have not been identified, and, consequently, the strength of chelating agents was not evaluated. Particularly in this instance the low expected concentrations were invoked, which, as noted in the preceding paragraph, is not viewed by this reviewer as appropriate for eliminating this potential compromising effect from consideration. On the other hand, in respect to the ESF, any chelating agents produced are expected to move downward with the consequence that their effects are greatly diminished. This does not eliminate the concern with respect to organic materials and microorganisms that may be introduced directly into the repository during construction.

West's report also considers the effects of concretes and grouts, citing results from Fernandez, et al. (1988). These are evaluated in the review of the latter report rather than here.

4. Consideration of data uncertainty.

Data uncertainty was taken into account qualitatively by specifying estimated ranges of values. No uncertainty or sensitivity analysis was performed.

5. Use of the analyses to form conclusions in 8.4

The conclusions drawn are cited above in section 2. As indicated in that section and section 3, these conclusions seem reasonable, although sometimes for different reasons.

Conclusions: Based on my review of the document referenced, I consider the data used appropriate, and for the most part the analytical methods used were also appropriate. Where inappropriate, other considerations were judged to be adequate to avoid invalidating the conclusions. The use of this report to support the conclusion that materials, especially liquids and gases, used or produced during ESF construction and testing will remain localized is judged to be reasonable.

Recommendations: 1) The recommendations on pages 40-41 of West (1988) should be followed, if they are not already implemented.

2) Plans for chlorinating J-13 water at the well should be changed. All chemicals added should be reviewed carefully for potential impact on the repository before being used.

3) Differences in rationale between this review and the report should be reconciled, and, if this results in any differences in the rationale deemed appropriate for support of the conclusions drawn, the revised logic should be formally documented.

4) During site characterization data should be measured to replace the estimates made in the report and the impact, if any, on the conclusions evaluated. This may in turn dictate repository design changes.

5) The designers of the ESF, H&N and F&S, should review Table A-1 in West (1988) carefully to determine whether there will be any other materials used that are not already identified.

6) All materials that will enter the repository that have not already been evaluated should be subjected to the same process as described in West (1988).

7) This reviewer believes that some simple preliminary tests of penetration of gases produced by explosives and of solvents and hydrocarbons should be made prior to starting tests in the ESF that would be sensitive to contamination by these materials. These could be as simple as deliberately spilling the solvents and hydrocarbons on a block of similar welded tuff at some locality remote from the site and, after some months, slicing the block to measure the penetration. Similarly, the penetration of explosive gases could be investigated in conjunction with planned further work at G-Tunnel, or even from existing openings with no additional blasting.

Paul F. Cloke 1/23/88

United States Department of the Interior

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IN REPLY REFER TO:

WBS#: 1.2.5.2.1
QA : "QA"
January 13, 1989

August Matthusen
Science Applications International Corp
Suite 407 101 Convention Center Drive
Las Vegas, NV 89109

Dear Augie:

Enclosed are four letters that were prepared as a result of reviews that were conducted as part of the Technical Assessment Review (TAR). The reviews, which were made for the TAR subcommittee on "Comparative Evaluation of Alternative ESF Locations", were used to evaluate whether appropriate conclusions are made in Section 8.4.3 of the SCP regarding the effects of the exploratory shafts on the waste-isolation capability of the Yucca Mountain site. The letters provide results of reviews that were made on parts of Section 8.4.3 of the SCP, Fernandez et al. (1988), and West (1988). I am transmitting copies to you because they may have a bearing on the findings of your subcommittee on "data reasonableness".

In general, the reviewers conclude that: 1) the models, assumptions, boundary conditions, and data inputs that were used in the analysis were reasonable and appropriate; 2) data uncertainties were considered and conservative approaches were taken; 3) the conclusions that were drawn were reasonable and appropriate; and 4) the conclusions were utilized appropriately in the judgments made of the potential impacts of the ES on performance.

The reviewers raised certain technical points that, if proven to be valid, could impact design. In addition, in some cases, additional or alternative technical approaches or models were suggested. Generally, the technical concerns raised are expected to be compensated for by the conservative measures that will be taken in design. These concerns do not reflect adversely on the Title I design approach but should be considered in Title II.

Sincerely yours,

William E. Wilson

William E. Wilson
USGS/Yucca Mountain Project

Enclosures
WEW/pnb
TAR.WEW

arrived 1/10/89

SAIC

Science Applications International Corporation
An Employee-Owned Company

December 28, 1988

D. Dilles 1-3-89

WBS: 1.2.3.3.6.2
QA: "QA"

W.E. Wilson III
Yucca Mountain Project Branch
U.S. Geological Survey
P.O. Box 25046, MS-421
Denver Federal Center
Lakewood, Co 80225

Subject: Review of West (1988)- NNWSI ESF Fluids and Materials Evaluation

Dear Bill:

In West (1988), a study was conducted to determine if any fluids or materials used in the Exploratory Shaft Facility will make the mountain unsuitable for future construction of the repository. The study consisted of compiling a data base of all fluids/materials to be used in the ESF and evaluating the impact by a decision tree analysis approach. Also, as part of the report, evaluations were made of the amount of water that will be lost during the excavation of the shaft, the distance the water will travel into the side walls of the shaft, and the amount of radionuclide movement caused by microorganisms. These evaluations were made by reviewing reports published by other NNWSI participants. For example, to evaluate water transport, reports by Klavetter and Peters (1987), Bodvarsson et al (1987), Eaton and Peterson (1987), Fernandez et al (1988), Daily and Ramirez (1987), and Kwicklis and Hoxie (1987) were evaluated. These reports were briefly summarized in the text (1 or 2 paragraphs), and in general, did not include enough information on input data, assumptions, boundary conditions, etc. to evaluate the accuracy of the results. Based on the results of these reports, West made conclusions and recommendations; some of which were referenced in the SCP. In the following paragraphs, I have summaried the findings of my review.

1. Based on reports by F&S, SNL, and REECo, West concluded that a value of 10% should be selected for the amount of drilling fluid that will be lost to the surroundings as a result of shaft excavation and drifting. This does not appear to be a conservative value based on the information provided on pages 128-131 of her report. For example, it is stated that F&S's borehole logs of G-4 suggest that an average figure of over 70% fluid loss is more correct than 10%. F&S's evaluation of fluid loss during drifting is only as low as 10% when drifting downward at a steep grade (-8%). When drifting upgrade, F&S stated that the fluid loss could be higher than 50%. Coppages' estimates of drilling fluid loss are unsubstantiated in West (1988), and could only be evaluated by going back to the reference; however, West does include Coppages recommendations on how to reduce fluid losses. His suggestions seem reasonable except for "avoid drilling into fractures". Roger Zimmerman's evaluation assumes a rock mass acceptance of 7% which is unsubstantiated in West's summary of his work. A review of his calculations would be required to evaluate his conclusion. In any

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event, it does not appear that anyone has modeled the problem: and thereby, taken into account the effects of a range of aperture distributions, matrix imbibition, etc.

2. Based on a review of water transport reports, West concluded that "the water would not penetrate very far". This is probably true for the matrix but not necessarily for the fracture system. Based on fracture-matrix modeling, Kwicklis and Hoxie (1987) point out that the distance the water may travel within the fractures depends on the imposed boundary head and on the largely unknown hydraulic properties of the fractures. They conclude that "although the introduction of drilling fluids may not produce a significant impact locally on the matrix in situ condition, a pronounced effect could be produced within a hydraulically well-connected fracture system."

   Despite her conclusion that water will not penetrate very far, West takes a conservative approach in her recommendations on the water transport issue by supporting the USGS position that: (1) dry mining techniques should be used for the rooms and adjacent portions of the access drifts within 100 ft from the center of either room and (2) minimal-water techniques should be used in the excavation of any underground opening that falls within a spherical radius of 300 ft from the center of the Bulk K room. However, this should be updated to use minimal-water techniques throughout the main level since four locations are now planned for the Bulk K Test and the exact locations can not be determined until after excavation (after the fracture system is exposed).

3. The results of the decision tree analysis identified hydrocarbons and solvents as the only two major categories which could have potentially significant effects on location suitability. West points out that interactions between hydrocarbons and solvents will tend to lower the viscosity of liquid hydrocarbons, enabling them to be carried deeper into the formation. "However, based on hydrological analyses, West predicts that the depth of penetration will not amount to more than a few centimeters" (quoted from SCP). This quote is only true if the fracture system is not taken into account, as discussed in comment 2. West concludes that the use of hydrocarbons and solvents should be restricted, which is an appropriate conclusion having taken into account the fracture system.

Sincerely,

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

S. G. Doty
cc: R. L. Wise, SAIC-Golden
    T. G. Barbour, SAIC-Golden
    Project File: 527-32-1-1

11-Jan-1989

Joe R. Tillerson

Joe R. Tillerson

Review of: Zimmerman, R. M., R. A. Bellman, Jr., K. L. Mann, D. P. Zerga, M. Fowler, and R. L. Johnson, 1988, G-Tunnel Welded Tuff Mining Experiment Evaluations, SAND87-1433, Sandia National Laboratories, Albuquerque, NM. (SAIC Ref. # ????)

Data Reasonableness

1. Based on my review of the document, comparisons with RIB data, and my familiarity with results of other rock mechanics data obtained for the YMP, I conclude that the data reported and used in this document are reasonable.

The data used were related to the application of the rockmass classification systems (CSIR & NGI) and to the linear elastic finite calculations. The analyses were specifically directed at G-tunnel applications but are reasonable for use in Yucca Mountain simulations.

The data obtained in the tests consisted primarily of data from tape extensometers, MPBXs, and water flow data taken in boreholes. Observations were also made regarding the effectiveness of blasting, the problems associated with grouting of rock bolts, and slabbing of the walls of the drifts. These data are all relatively straightforward measurements and appear, in my opinion, to be reasonable. The conclusion of reasonableness is further supported by comparisons made in the report with the results of analyses (see Appendix A) and with test results obtained in other tests in both G-tunnel and other formations.

Reasonableness of Analysis Methods

1. Both the rock mass classification methods and the linear elastic finite element methods are, in my opinion, reasonable for use in simulating the response of welded tuff.

In the report, the limitations of the use of the methods are identified and discussed. The analysis results are compared with the observed behavior of the tuff and the support system and it is concluded that the observations are in general agreement with the trends and types of behavior observed in the model predictions. The absolute magnitudes of the displacements differ by about a factor of 2-2.7 from the predictions and extensive discussions are provided to explain possible reasons for such variations.

Treatment of Uncertainty

1. Uncertainty is appropriately and adequately treated in the analyses and in the interpretation and evaluation of the measurements.

11-Jan-1989

The treatment of uncertainty is an inherent part of the design and evaluation of the experiment. For example, the variety of instrumentation and the number of stations chosen for the measurements are directly related to attempting to understand the variability and uncertainty in the response of the tuff to excavation. The authors clearly recognized the potential influence of the fault that was observed in the drift, the limitations that existed because of drift length, problems in blasting and bolt installation, and problems in using resin grouted bolts in a repository. They evaluated uncertainties related to the two-dimensional nature of the calculations, the timing of when the instrumentation was installed, and the potential for underpredicting drift displacements using elastic analysis methods. Two methods of displacement measuring were used and two approaches to looking at the extent of the modified permeability zone that results from drift construction were evaluated. They clearly listed limitations and uncertainties in borehole injection measurements and identified that the approaches used were incapable of identifying the blast damage effects since they generally occur so near the face of the excavation. Even the analysis approaches considered uncertainties since two different rock mass classification systems were used and the structural calculations were modeled with and without a damage zone

Appropriateness of Analysis Use in ESF Title I Evaluations

1. The data and analyses are appropriately used in the evaluations of the ESF Title I design that are documented in SCP section 8.4; the report provides unique support for the evaluations since not only are analysis results available but data measured in field evaluations are supportive of the evaluations of the Title I design.

In section 8.4.2 of the SCP the report is appropriately referenced as supporting the use of the elastic material model and as supporting the conservativeness of the standoff from drifts as regards the extent of disturbance. In section 8.4.3, the report is appropriately used to indicate that little joint displacement (opening) was evident except within 1-2 m of the opening.

Recommendations: None

APPENDIX J

Report on

Comparative Evaluation of the Waste-Isolation
Capabilities of Alternative Locations
for Exploratory Shafts

Comparative Evaluation of the Waste-Isolation
Capabilities of Alternative Locations
for Exploratory Shafts
at Yucca Mountain, Nevada

A report prepared in support of Technical Assessment Review:
Exploratory Shaft Facility (ESF) Title-I-Design-Acceptability Analysis
and Comparative Evaluation of Alternative ESF Locations

January 1989

Concurrence:

2/1/89
Scott Sinnock   Date

2-1-89
Bill Wilson   Date

2/1/89
Jeff Kimball   Date

2/1/89
Scott Van Camp   Date

2/1/89
Felton Bingham   Date

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Comparative Evaluation of the Waste-Isolation Capabilities of Alternative Locations for Exploratory Shafts

1 Purpose of This Report

In its efforts to characterize Yucca Mountain, Nevada, as the site for a radioactive waste repository, the U.S. Department of Energy (DOE) intends to investigate the geologic formations that would be part of the proposed repository system. Some important parts of the investigation are to be conducted by means of two shafts and associated drifts being built into those formations. In 1982, the DOE selected a construction method and a location where one or more of these exploratory shafts would be built. The selections were guided by processes described in a report by Bertram (1984).

The selection of the shaft location was accomplished by applying a set of criteria to the entire block proposed for characterization as a potential repository site. The application of these criteria identified five preferred locations. The final selection of a single location was accomplished by applying a more detailed set of criteria and arriving at a figure of merit for each of the five preferred locations. The report by Bertram describes the criteria and the selection process in detail.

The shafts and drifts will only be used for characterization of the site; no waste will be emplaced in them or closer to them than 30 meters. The criteria used in the selection process did not explicitly include the ability of the locations to isolate emplaced waste from the environment. Instead, the criteria were intended to ensure that constructing shafts at the location would provide access to the geological features being investigated, be technically feasible, and produce no adverse environmental effects that could not be mitigated. In retrospect, some of the selection criteria can be seen to be implicitly relevant to waste isolation. One criterion, for example, required that the shafts not be in an area where potentially adverse conditions were thought to prevail. Investigation of potentially adverse conditions was not precluded; a separate criterion required that the shaft be near enough to potentially adverse features to make access to them available for exploration by further underground excavation or horizontal drilling. The criterion for avoiding potentially adverse conditions was intended to make sure that the shafts provided access to the kind of rock in which the repository might be built. Nevertheless, it also tended to favor locations with a waste isolation capability that would not be affected by potentially adverse conditions.

After the shafts are used for characterization, they will become a part of the repository if the Yucca Mountain site is selected for development. The DOE decided, after the Bertram study, that although no waste would be emplaced in or near the shafts, they would be used for ventilation and for emergency egress during the period when waste is being emplaced in the repository (DOE, 1988, Section 6.2.5.1.3); afterwards, they would be backfilled and sealed to the extent necessary (DOE, 1988, Section 8.3.3.2). In reviewing the location selection process, the U.S. Nuclear Regulatory Commission (NRC) suggested that, in view of this possible future role of the shafts as part of the repository, it would be advisable to examine the waste isolation capability of the preferred locations identified in the Bertram report.

To meet the preapplication review requirements of 10 CFR Part 60, paragraphs 60.15(d)(1) and 60.17(a)(2)(iii and iv), the DOE evaluated the potential impact of an exploratory shaft facility (ESF) on the ability of the ESF location to isolate waste; Section 8.4.3 of the Yucca Mountain Site Characterization Plan (DOE, 1988) was a product of that review. The review described in this document focuses on evaluating the relative differences among the alternative locations and the influence the ESF may have on the ability to isolate waste. In reviewing alternative locations, other reasons for selecting a location should also be considered. It may be advisable to study the geological formations in an area that, while thought to be suitable for a repository, also allows the testing program to thoroughly address uncertainties in the site characteristics that appear to be the most adverse to the suitability of the site. If after site characterization such an area does prove suitable for a repository, the testing will have provided additional confidence that the other parts of the site are also suitable. Putting a shaft into the area thought to provide the best isolation capabilities could, in principle, leave unresolved the questions that might be raised about the suitability of the rest of the site. It is for this reason that this report examines waste isolation capability, in addition to the reason underlying the NRC suggestion.

This report responds to the NRC suggestion by examining the capability of each of the five preferred shaft locations identified by Bertram (1984) to isolate waste from the environment. Chapter 2 does so by reviewing the available data on the site characteristics that are the most important in providing waste isolation. That chapter compares the five locations on that basis; it also compares the characteristics of the locations with the range of characteristics that exists across the site. Chapter 2 then draws some conclusions about the effect that an explicit waste isolation criterion would have had if it had been a part of the process for selecting a location for exploratory shafts. Chapter 3 reviews the effects that a shaft at any of the locations would be expected to have on the waste isolation capability of that location. The review is principally a summary of the extensive discussion of those effects identified in Section 8.4.3 of the site characterization plan (SCP) (DOE, 1988). The final chapter of this report discusses the regulatory implications for the siting of an exploratory shaft and briefly summarizes the conclusions reached in the second and third chapters.

2 Comparison of Waste Isolation Characteristics

2.1 Background

The purpose of this section is to augment information in Bertram (1984) concerning the screening of locations for an exploratory shaft at the proposed Yucca Mountain repository site. Specifically, this section compares potential shaft locations identified in Bertram (1984) on the basis of their capabilities for postclosure performance, building on methods used in 1981 to identify shaft siting criteria consistent with siting criteria in 10 CFR Part 60 (Lincoln, 1981).

As recognized in 1981 (Lincoln, 1981), the location of an exploratory shaft could influence both actual performance and the ability to predict accurately the performance of the repository system. Influences on the actual performance should be considered in location selection to help insure that the construction and operation of the shaft do not jeopardize the ability of the engineered barriers or the site to perform their intended functions of containment and isolation of the radioactive waste. The potential effects of the shaft on performance must also be considered in the context of the effects of construction and operation of the repository, which may be much greater than those of the shaft itself. Therefore, at this stage of the program, the principal concern is the various effects the shaft may have that are deleterious and that are different from those expected from the repository itself. Influences on the ability to predict performance must be considered in the context of the main objective of the exploratory shaft, which is to provide information about site characteristics upon which the predictions of performance, as well as design of the underground facilities, will be based.

Previous contractor studies for the DOE implicitly considered this tradeoff and recommended shaft locations that were considered to be the most effective in obtaining relevant information about site characteristics (Lincoln, 1981; Bertram, 1984). However, these earlier studies, particularly Bertram (1984), did not explicitly establish the relationship between performance potential and the site characteristics targeted for exploration by a shaft. Thus, the potential performance of a particular ESF location was not a factor in the selection of a location. Nor did these studies explicitly account for the relative effects of the shaft on performance at the alternative shaft locations, though the effects of construction fluids on hydrologic and geochemical properties were considered in the recommendation for a shaft construction method, independent of location (Bertram, 1984). Additional data have become available since those studies were completed and technical understanding has matured about the site characteristics most relevant to postclosure performance. Therefore, it is now prudent to evaluate the impact that consideration of performance could have had on location selection of the shaft location.

The method for this evaluation uses available information to assess the similarities and differences in potential postclosure performance among the general areas representing the five alternative shaft locations considered in the final screening of the Bertram (1984) report. An additional comparison is made with the southern part of the repository area, which was not considered in the final comparisons of the Bertram report. Both comparisons are done in the context of the potential variability of performance across the entire repository area, defined to be a rectangular area enclosed by the perimeter drift of the conceptual repository design (SNL, 1988), and the five alternative shaft locations (Figure 1). The objective of the comparison is to document any relative differences in location performance, identify the underlying site characteristics that account for the relative differences, and qualitatively discuss the extent to which a shaft at each location would be likely to provide information about those characteristics. These discussions consider the possibility that the site characterization data from an alternative location may be less effective in reducing uncertainty about potential failure modes than data from the present location.

When comparing "performance potential" at selected locations within the entire site, as represented by the alternative shaft locations, it must be remembered that performance in terms of the regulations accounts for the combined effects of all locations where waste will be emplaced. Because no waste will be placed within the shaft facilities, these locations will not even contribute to system performance, especially for containment and controlled releases from the waste package. They may contribute to total system performance, but only if transport pathways from the waste go through the shaft facilities. Therefore, in a strict sense, performance is a concept that cannot be applied to an individual restricted location such as a shaft site. However, we can compare the variability of certain characteristics and processes that affect system performance among alternative shaft locations and consider any differences as differences in performance influencing factors. In this light, a "good" or "poor" "performing" shaft location does not necessarily imply anything about the performance qualities of the overall mined geologic disposal system.

However, if one were to assume, in a conservative fashion, that conditions of the poorest performing shaft location represent the most likely failure modes for the site as a whole, then differences among the locations can be used as an important guide to shaft-site selection. In this approach, the poorest performing locations are the most desirable to allow reduction of uncertainty through in situ characterization for the condition considered most critical for establishing the lack of failure modes. Therefore, because no assessments of postclosure performance of the total system or its subsystems are yet available that would allow direct comparison of the relative contributions to performance of alternative shaft locations, a set of site characteristics that are inferred to serve as reasonable surrogates for engineered barrier, site, and total system performance is established in this report. These surrogates are used to assist in reaching an overall judgment about whether any relative differences among potential contributions of alternative shaft locations are significant.

This chapter contains four sections. Following this background discussion, Section 2.2 identifies several site characteristics that serve as surrogates for comparing postclosure performance relative to the performance objectives of 10 CFR Part 60.112 and 60.113. Section 2.3 compares these surrogates for the alternative shaft locations identified by Bertram (1984) in the context of their variability across the entire repository site. This section also addresses the requirements for elements 1 and 3 of Part II (paragraphs 2.5.1 amd 2.5.3) of the plan for the Technical Assessment Review.

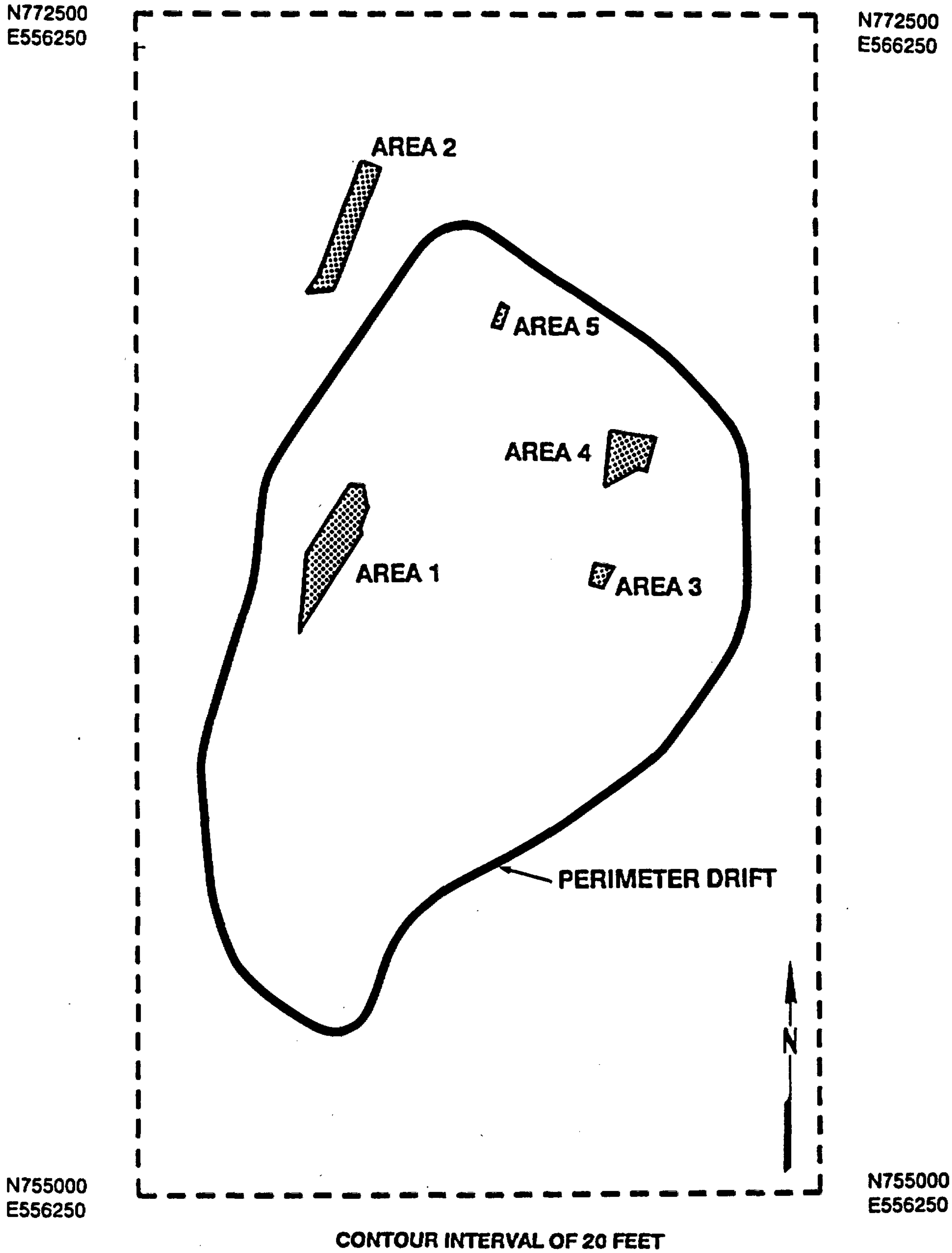

Figure 1. Area considered in the comparison of alternative shaft locations.

Section 2.4-draws conclusions about the selected shaft location on the basis of these comparisons.

The technical discussion that follows is written under the assumption that the reader is knowledgeable about the general geological, geochemical, and hydrologic features of the Yucca Mountain site, and about the location and design concepts of the repository facilities as described in the SCP. The reader is also assumed to be knowledgeable about applicable U.S. Environmental Protection Agency (EPA) and NRC regulations for geologic repository systems. If more background information is required, the reader is referred to the SCP, its references, 10 CFR Part 60, and 40 CFR Part 191.

2.2 Relation of selected site characteristics to postclosure performance

This section establishes a set of selected site characteristics that is used in Section 2.3 for comparing the performance potential of the alternative shaft locations. The discussion is divided into three subsections that describe site characteristics for hydrologic (Section 2.2.1), geochemical (Section 2.2.2), and thermal mechanical (Section 2.2.3) influences on nominal postclosure performance. One additional subsection describes site characteristics that may influence the effects on performance of selected scenarios for disturbed conditions (Section 2.2.4). A summary of the site characteristics identified for use in the shaft location comparisons and their relations to performance with respect to the postclosure performance objectives of 10 CFR Part 60 is provided in Section 2.2.5.

2.2.1 Hydrologic influences on nominal, undisturbed performance: flow in fractures and subordinate surrogate characteristics

Postclosure performance of both engineered and natural barriers depends on the values of certain site characteristics that vary throughout the site. These performance influencing variables are identified in the performance allocation tables of the SCP for Issues 1.1, 1.4, 1.5, and 1.6 (SCP Sections 8.3.5.13, 8.3.5.9, 8.3.5.10, and 8.3.5.12, respectively). Foremost among these is the quantity of moving water (flux) at and below the repository level and its mode of movement (i.e., whether the water is moving in fractures or in the matrix pores of the rock). The potential for flow in fractures is a special concern, because this flow mode could provide a mechanism for (1) transferring water to the waste containers by seepage from the rocks causing dripping across air gaps within the emplacement boreholes and (2) rapid movement of radionuclides by ground water through the unsaturated zone to the saturated zone underlying the repository. The former process could enhance the rate of container dissolution, subsequent waste form dissolution, and resulting radionuclide releases to the site. The latter process could result in ground-water flow times that are shorter than those required for adequate waste isolation by the regulations. However, if ground-water flow is predominantly in the pores of the rock matrix in the unsaturated zone (as discussed in Sections 8.3.5 and 8.4 of the SCP), then concerns about different performance potentials among alternative locations are diminished. Under this case, little or no water would be able to contact the emplaced waste, allowing it to dissolve and to be released to the surrounding rocks; and flow times for carrying any released waste to the underlying water table would probably exceed the period of concern for performance.

Though the physical mechanisms that determine the relations between flow in matrix and flow in fractures in unsaturated rocks are only partially understood, the evidence strongly indicates that the likelihood of sustainable flow in fractures decreases rapidly as the flux decreases below some critical value in relation to the maximum transmitting capacity (saturated hydraulic conductivity) of the porous matrix of the unsaturated volcanic tuffs. Current evidence suggests that if the ratio of flux to saturated matrix hydraulic conductivity decreases to some value between about 0.5 and 1.0, the likelihood of significant flow in fractures becomes substantially lower (Dudley et al., 1988). Thus, the ratio of flux to matrix conductivity, through its relation to fracture flow, is a useful surrogate characteristic that is directly related to performance, as expressed by the regulatory postclosure performance objectives for containment, controlled releases, pre-waste emplacement ground-water travel time, and total system performance (10 CFR Part 60.112 and 60.113). Where this ratio is large relative to other locations, the potential for flow in fractures and associated poorer performance is greater.

For pre-waste emplacement ground-water travel time, this ratio, or any other spatially varying surrogate for comparing performance potential at alternative locations, may be relevant only insofar as it helps identify the location of the "fastest path of likely radionuclide travel" (10 CFR 60.113). This path, in all likelihood, is restricted to a small portion of the repository area, regardless of the location chosen for the shaft. Therefore, performance, per se, for pre-waste emplacement ground-water travel time may not be applicable at or near any of the alternative shaft locations. For the regulatory objective, the ratio is significant in that it affects ground-water velocity and, thus, radionuclide transport time. For containment and controlled releases, this ratio is important in the Topopah Spring host rock because it affects the likelihood and quantity of water that would be able to seep or drip from the rocks onto the waste containers.

An improved understanding of the implications of this critical ratio for shaft siting is gained by considering its potential variation throughout the complex three-dimensional geometry of the site, as affected by surface topography and the geometry of relatively distinct hydrostratigraphic units (Montazer and Wilson, 1984; Sinnock et al., 1986) and structural features (Scott and Bonk, 1984) that occur at the site. Both matrix hydraulic conductivity and flux vary across the site, so the potential variability of each must be considered. Though these two variables are closely, and probably functionally, related, for convenience they are considered separately in the following discussion.

Information about saturated matrix hydraulic conductivity is available for most of the hydrostratigraphic units. Though variations within the units have been observed, current evidence is insufficient to establish any systematic trends. Therefore, the matrix conductivity within each unit is assumed to be uniform and nondiscriminating. However, differences in matrix conductivity among units are well established (Peters et al., 1984). Generally, and for the purposes of this report, the saturated matrix conductivity of each unit may be considered as either small (less than 0.1 to 1.0 mm/yr, or about 3×10^{-12} to 3×10^{-11} m/s), for the densely welded units, or large (greater than 10 mm/yr, or about 3 X 10^{-10} m/s), for the partially welded to nonwelded units (RIB, 1987). A greater thickness of large-conductivity (nonwelded) units is more desireable than a greater thickness of small-conductivity (welded) units, through which flow in fractures is more likely. However, if the flux were generally below the threshold for flow in fractures, a likely scenario even in the densely welded units, then the distinction between large- and small-conductivity units would be less discriminating. In this situation, the total thickness of the unsaturated zone below the repository may be a discriminating factor for the ground-water-flow component of potential radionuclide transport because flow times would be related to total distance of unsaturated flow, assuming moisture contents are generally constant.

In contrast, total rock-mass saturated conductivity probably is greater in the densely welded units (perhaps up to 400,000 mm/yr, or about 10^{-5} m/s), because of the abundance and openness of connected fractures. The presence of less abundant, and perhaps less open, fractures in the nonwelded units probably results in smaller rock-mass conductivities. However, rock-mass conductivities are important only if the unsaturated rocks can sustain flow in fractures, which is assumed to occur only where or when the flux approaches the saturated matrix conductivity, as discussed above.

The ranges of saturated hydraulic conductivity of "matrix" materials within fault zones or other structural features are unknown, but the conductivities are assumed to be similar to or less than those of the surrounding rocks. The conductivity of "matrix" materials in fault zones is likely to be less, particularly in the "large conductivity" nonwelded units, where clay gouge or gangue materials may occur. However, fracture frequencies are likely to be significantly greater in and near fault zones, so the area of fracture-matrix interfaces is likely to be much greater in fault zones, as is the fracture-dominated rock-mass conductivity.

In summary, variations in saturated matrix hydraulic conductivity throughout the site are considered in this report by using (1) lower-level surrogates of the three-dimensional geometry (thickness and distribution) of discrete hydrostratigraphic units with relatively large or small conductivity and (2) the location of known structural features (faults) that may act as conduits, with large rock-mass conductivity, for vertical, perhaps rapid, water flow through the unsaturated zone. Faults that are composed of small-conductivity fill materials may also be barriers to flow, but for the purposes of this analysis, faults are only considered as potential conduits for vertical flow.

No direct observations of flux variations have been made across the site; therefore, indirect evidence has been used to infer its potential magnitude and spatial variability. Average flux across the site beneath the repository horizon is conservatively estimated to be less than about 0.5 mm/yr on the basis of several lines of evidence, as described in Section 3.9.3.4 of the SCP (DOE, 1988). Actual flux values are likely to vary within each hydrostratigraphic unit and between individual units. Two major sources of potential variability currently are identified: (1) down-dip lateral diversion and concentration of subsurface percolation in one or more hydrostratigraphic units and (2) concentration of infiltration at the surface due to variations in topography, patterns of precipitation and associated runoff, and infiltration characteristics of surficial units. Thus, flux may be considerably less than 0.5 mm/yr beneath some parts of the site, and considerably greater in localized zones of concentrated flow.

Down-dip lateral diversion, if it occurs, probably is related to contrasts in hydraulic conductivity at unit contacts, and possibly to anisotropy of conductivity within units and vertical drainage of accumulated concentrations along fault conduits. If lateral diversion occurs, it would cause smaller average flux values in units underlying the surface of diversion, except, perhaps, locally along faults that may serve as vertical drains.

The distribution of surface infiltration probably is largely controlled by topography. Infiltration may occur along surface drainage channels, where episodic storm runoff is concentrated, or along upland ridges, where more gentle rainfall or snowmelt may slowly percolate directly into open fractures (de Vries, 1988). In all cases, structural features, especially surface or near-surface faults, may intercept the flux and provide conduits for downward movement of concentrated quantities of water. Local variations in precipitation and the characteristics of surficial units probably also influence flux distributions, but few data for these parameters are available and their relative influences are unknown.

To infer some reasonable scenarios for flux distributions across the site, this report uses the same lower-level surrogates for performance as for hydraulic conductivity, namely the three-dimensional geometry of the subsurface hydrostratigraphic units and the location of structural features. An additional surrogate, surface topography, is also used. In this case, however, the three-dimensional geometry of the units is represented by the down-dip position rather than by the thickness.

Figure 2 shows the general relationships among site characteristics that influence the likelihood of flow in fractures. This figure summarizes the logic that establishes mappable surrogates for performance (lower levels of the figure) relative to the performance objectives for engineered barriers, the site, and the total system (upper level of the figure). These surrogates provide a basis for comparing potential performance at alternative locations with respect to the dominant influence of flow in fractures on uncertainty about repository peformance over the long term. Several lesser influences on performance uncertainty are addressed in the following sections and summarized for nominal, undisturbed performance in Figure 2.

2.2.2 Geochemical and mineralogic influences on nominal, undisturbed radionuclide releases and transport

The speed and quantity of radionuclides released from the waste package and their subsequent movement toward the water table and accessible environment will be affected by the chemistry of the water and rocks in the emplacement environment and along the potential transport pathways from the repository. Only slight variations among the shaft locations are expected with regard to natural or repository-influenced chemistry of water potentially contacting the waste packages. This uniformity is expected because the waste

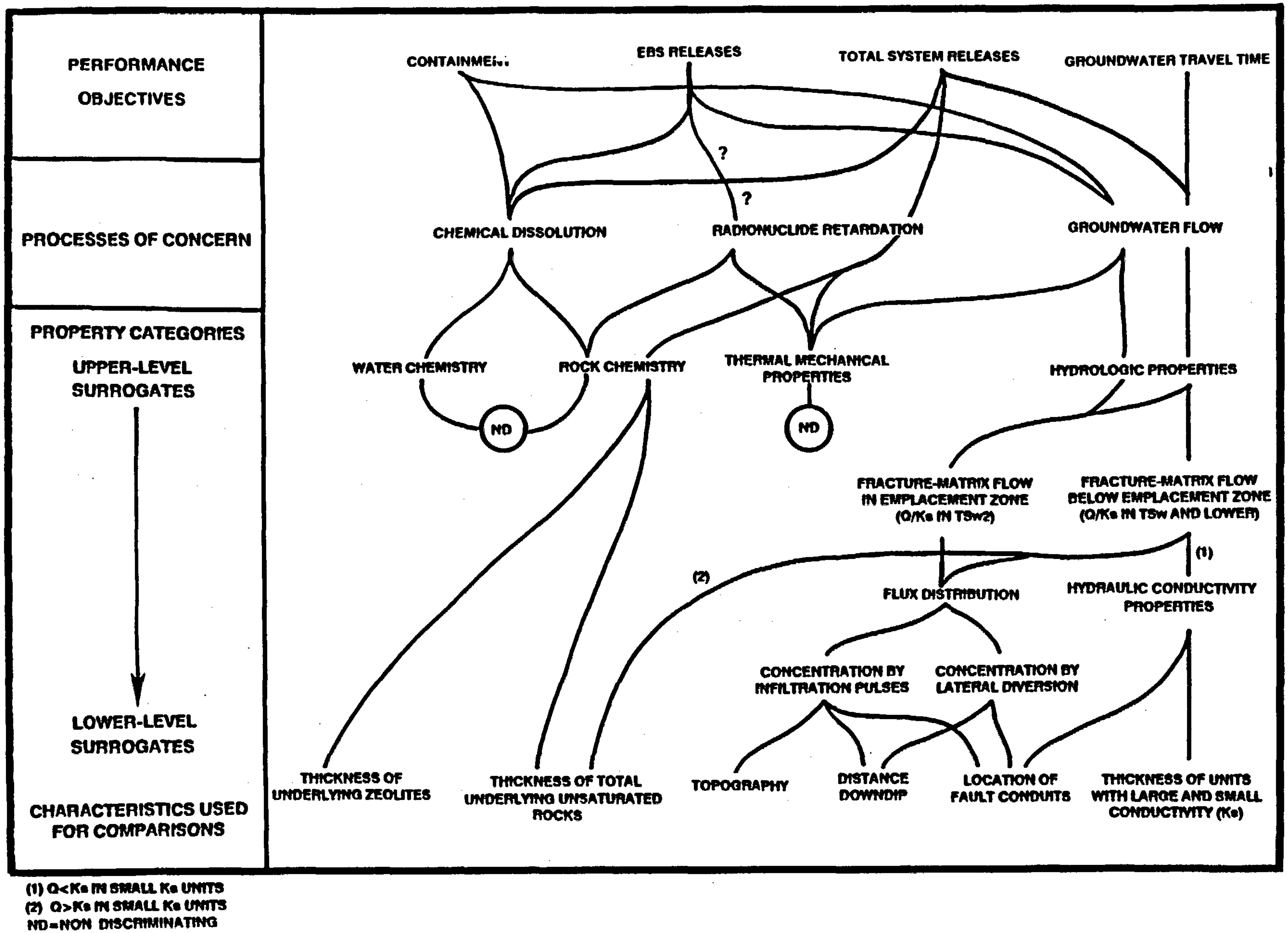

Figure 2. Logical representation of relations between performance objectives, and surrogate site characteristics.

Table 1. Categories of scenarios delineated according to potential impacts on barriers of the geologic repository (scenario classes). (Taken from SCP Table 8.3.5.13-3)

Disturbed performance of barriers.

(A) Direct Releases:

1) direct release in an extrusive magmatic event;

2) direct release associated with human intrusion

(B) Partial failure of engineered barriers[a]

(C) Partial failure of unsaturated zone barriers:

1) accelerated releases to the water table attending increased flux from sources above the repository;

2) accelerated releases to the water table attending a rise in the water table (foreshortening of unsaturated zone);

3) accelerated releases to the water table attending changes in unsaturated-zone rock hydrologic properties or geochemical properties.

(D) Partial failure of saturated-zone barriers:

1) accelerated releases to the accessible environment owing to appearance of discharge points within 5 km downgradient of controlled area (foreshortening of the saturated zone flow path) or changes in flow direction in saturated zone.

2) accelerated releases to the accessible environment owing to increased linear water velocity in the saturated zones, changed rock-hydrologic properties, or changed geochemical properties.

Undisturbed and nominal performance of all barriers.

(E) Undisturbed performance of all natural barriers: (matrix flow predominates in unsaturated-zone barriers, some carbon-14 released in gas phase)

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[a]No independent, potentially significant classes have been associated with this category.

randomly oceurring event in the repository area and because the depth of drilling will be assumed sufficient to penetrate the repository, no site characteristics are considered discriminating with respect to either the probability or consequences of human intrusion scenarios. Perhaps the level platform of the pad for the shaft would entice the siting of future drill-holes at any shaft location, if original land contours are not restored, but this would apply to all locations equally. If future drilling were undertaken to explore for water resources, the depth to the water table might discriminate among alternative locations, but in this case a future driller would probably choose locations away from the high relief, montane repository area and drill at sites where the water table is almost self evidently closer to the surface. Though acknowledged as possible discriminators, these factors are not used in this report, because no characterization from the shaft activities can reduce the uncertainties attributed to these factors, nor are potential effects of the shaft on these factors likely to discriminate among the alternative locations.

2.2.4.3 Partial failure of engineered barriers (scenario category B)

No independent, significant classes of scenarios have been associated with this scenario category at this time (Doe, 1988, Table 8.3.5.13-3). As a result, no site characteristics are discriminating in terms of probability or consequences of this category of scenarios.

2.2.4.4 Accelerated releases to the water table attending increased flux from sources above the repository (scenario category C1)

Ten types of initiating events are identified in the SCP for this category of scenarios, but only two are considered sufficiently consequential to merit further consideration: (1) climate change causing an increase in net infiltration and (2) fault offset increasing local flux concentrations related to downdip lateral diversion above the repository (DOE, 1988, pages 8.3.5.13-84 and -86). Changes in infiltration would tend to follow the same topographic patterns as current infiltration, so the spatial discrimination of performance potential addressed for flux in Section 2.2.1 also applies for changed flux due to climate change. In addition, the depth of the repository will affect the "waiting time" factor in Equation 8.3.5.13-23 of the SCP (i.e., the time for the climatic perturbation to propagate to repository depths); therefore, the thickness of overburden is a discriminating factor for potential performance among the alternative shaft locations with respect to the effects of climate change on potential performance for containment and isolation.

With respect to fault offsets creating preferential pathways for local concentrations of flux, the most likely zones of fault movement are along existing structures, which already are considered in discriminating flux and hydraulic conductivity across the site. Therefore, this category of scenarios can be accounted for in comparisons of potential performance by adding only the factor of thickness of overburden to factors previously identified for the nominal, undisturbed scenario category.

2.2.4.5 Accelerated releases to the water table attending a rise in the water table (scenario category C2)

The SCP (page 8.3.5.13-86) identifies nine types of initiating events that might cause the distance between the repository and the water table to change over the next 10,000 years. All performance scenarios under this category are concerned with a shortening of the distance from the repository to the water table, so a reasonable surrogate for this set of concerns is the total thickness of unsaturated materials below the repository. This surrogate characteristic varies considerably throughout the site and among the alternative shaft locations. It was identified in Section 2.2.2 as a factor to consider in relation to ground-water flow times through the unsaturated zone and the effects of geochemical retardation on radionuclide transport times. Some scenarios postulate that temporary water rises, perhaps of short duration, may occur through the repository along fault zones. The distance to faults, as identified in Section 2.2.1, would discriminate performance potential for this concern. Therefore, no new discriminating site characteristics are identified to account for the effects of water table rises on potential performance. Only if the water table were to rise to the level of the repository would this scenario be applicable to containment. Because such a large rise in the water table generally is considered unlikely, particularly away from fault zones where no waste would be placed, this scenario category is not applicable to the performance objectives for engineered barriers (which only apply under anticipated conditions).

2.2.4.6 Accelerated releases to the water table attending changes in unsaturated-zone hydrologic or geochemical properties (scenario category C3)

Current information in the SCP leads to a conclusion that no "events or processes are currently believed to be capable of leading to consequences distinguishable from undisturbed-case consequences" (DOE, 1988, page 8.3.5.13-88); therefore, no site factors are considered discriminating in terms of performance potential with respect to this category of scenarios.

2.2.4.7 Accelerated releases to the accessible environment due to appearance of discharge points within the controlled area (scenario category D1)

A water-table rise of more than 160 m would be required to cause the appearance of discharge points (springs) within the controlled area. Such a rise could be episodic and temporary, due to stress changes or other tectonic causes, or sustained, due perhaps to climate change and increased regional infiltration, faulting, or intrusion of a low permeability barrier down-gradient from the repository. The same factors that could account for a water-table rise to foreshorten the unsaturated zone barrier (Section 2.2.4.6) could serve to foreshorten saturated flow paths. This category of scenarios (appearance of discharge points in the controlled area) would relate to performance at alternative shaft locations through the horizontal distance to the new discharge point. Because no evidence exists to identify the locations or likelihoods of potential new discharge points within the controlled area, no discriminating factors are available for this scenario category in terms of potential performance differences among the alternative shaft locations. Also, a foreshortening of saturated flow paths beneath the repository is not applicable to performance of the engineered barriers in the overlying unsaturated zone.

2.2.4.8 Accelerated releases to the accessible environment due to changed saturated-zone hydrologic properties, including hydraulic gradient (scenario category D2)

No discriminating factors are available for distinguishing the total system performance at alternative shaft locations based on this scenario category. Also, changed properties in the saturated zone are not applicable to performance of the engineered barriers in the overlying unsaturated zone.

2.2.5 Summary of site characteristics used as surrogates for potential performance differences among alternative shaft locations

Insight into the usefulness of the surrogate site characteristics in representing waste-isolation capability can be gained by considering the relationships between those characteristics and the flow of ground water from the repository to the underlying water table. The flow of ground water is particularly important to waste isolation because it would be the principal mechanism by which radioactive material might leave a repository if the barriers against release were breached. For this reason, the performance-allocation tables in the SCP, as mentioned above, emphasize ground-water flux and its mode of movement. Most aspects of the surrogates have direct bearing on one or both of these characteristics of ground-water flow. Although the relationships have not yet been fully explored, computer simulations cited in SCP Sections 3.9.2 and 8.4.3.2; Dudley et al., (1988); Sinnock et al., (1986); Rulon et al., (1986); and Wong and Narasinhan (1986, 1988) have provided some basic understanding. The next few paragraphs summarize some of this understanding in order to provide further perspective on the use of the surrogates as indicators of potential for waste isolation.

The range of flow modes that, in theory, may occur at the Yucca Mountain site encompasses flow predominantly in matrix pores, flow in both matrix pores and fractures, and flow predominantly in fractures. Flow in fractures is considered a less favorable condition than flow in matrix pores, because it is usually faster; the shorter ground-water travel times that result from flow in fractures would be less favorable than the longer times resulting from flow in the matrix. For this reason, surrogates that suggest lower likelihoods for flow in fractures are indicators of locations with greater waste-isolation potential. Examining the surrogates over the entire range of flow modes is useful because it addresses potential differences among locations under the current conditions, in which matrix flow probably is predominant; under potential disruptive conditions that might increase flux enough to cause significant flow in fractures; and under alternative concepts of flow that describe significant flow in fractures under current conditions.

If the flow occurs predominantly in the matrix pores, the thicknesses of unsaturated rock units beneath the repository are obvious indicators of performance, because the greater the thickness, the longer the time taken for water to reach the water table if moisture content is generally constant. The total thickness of the unsaturated material is, therefore, a primary surrogate for performance under matrix-dominated flow. Among the five locations, however, the differences in this thickness do not appear to be significant because the ground-water flow times at the site are expected to be longer than the period of regulatory concern (10,000 years for the postclosure performance objective of 10 CFR 60.112) (Section 6.3.1.1.5 of DOE, 1986). Furthermore, most radionuclides would be retarded, relative to the ground-water flow times, by the minerals in the zeolitic, vitric, and devitrified units, and the transport times for these radionuclides would be even longer.

If the flow occurs partly in the matrix pores and partly in fractures, the surrogates are more likely to discriminate among the locations. Whether such flow conditions currently exist at the site, either locally or over a wide area, is not known. As a general rule, flow occurs predominantly in the rock matrix when the flux is substantially less than the saturated matrix hydraulic conductivity of the rock. When fluxes approximately equal the value of conductivity, flow in fractures becomes more likely, and both flow modes may occur simultaneously. Some conceptual models and disruptive scenarios include the possibility of these conditions: for example, some models describe lateral diversion of the flow at or near unit contacts, and some disruptive scenarios describe episodic, concentrated pulses of infiltration. If such conditions could cause concentrations of flux that are comparable to the saturated matrix hydraulic conductivity of the rock along the flow paths, flow in fractures would become likely. The surrogates that most closely indicate the possibility for such conditions to occur are 1) locations of faults, which might transmit large fluxes downward; 2) topography, which is assumed to influence the distribution of infiltration; and 3) downdip distance, which reflects the possibility that lateral flow, if it occurs, will produce greater fluxes in a downdip direction.

Even without these conditions of lateral flow or concentrations of flux, widely distributed flow in fractures may alternate with flow in matrix pores along any particular flow path. Such an alternation can occur when the local saturated hydraulic conductivity exceeds the local flux along some parts of the path and is less than the local flux along either parts. The possibility for flow in fractures under such conditions is greater in the units with smaller conductivity (TSw and CHnz). This could occur within any given unit characterized by local differences in hydraulic conductivity which can be represented by a probability distribution of conductivity for the unit as a whole. Spatial correlations and trends in the mean (nonstationarity) must be considered. Mixed flow in matrix pores and fractures is likely to occur when the flux is approximately as large as the mean saturated hydraulic conductivity of any unit--a value that currently is estimated to be less than 0.5 mm/yr for the TSw and CHnz. At such flux values, the flow in the other, large-conductivity units is likely to be predominantly in the matrix pores. The thickness of large-conductivity units is therefore a surrogate that indicates potential for greater performance (i.e. greater potential for matrix dominated flow along greater distances). Locations with the greater thicknesses of these units have the greater potential for waste isolation when flux is approximately the same as the mean saturated hydraulic conductivity of the small-conductivity units.

The conditions under which flow in fractures is initiated or sustained are not well understood. Nevertheless, it may be assumed that flow simultaneously in matrix and fractures is less likely where the flux-to-conductivity ratio is likely to be smaller--i.e., at locations where the large-conductivity units make up the larger fractions of the stratigraphic column. The total thickness of the unsaturated materials beneath the repository horizon is also a useful surrogate under these conditions, because travel time will be longer when the section is thicker, even if some flow is in fractures. Another useful surrogate is the thickness of the zeolitic units because of their ability to retard radionuclides. These three surrogates are therefore useful for qualitative comparisons among potential ESF locations under plausible conditions of local flow in fractures, although the current limited evidence suggests that flow at Yucca Mountain probably is predominantly in matrix pores, at least in the places where saturation measurements have been made. However, seepage of water into borehole USW H-1 observed in teleview logs suggests a possibility of high saturations and possible fracture flow conditions in some parts of the site though the seepage may be due to return of drilling fluids to the borehole.

The third flow mode in the range that is feasible at Yucca Mountain--flow predominantly in fractures--would require a concentration of flux that is much greater than the currently estimated average values for the site. In theory, such fluxes might arise from significant lateral diversion followed by flow through fault conduits or from locally restricted pulses of infiltration beneath washes or other areas favorable for infiltration. A likely consequence of such conditions would be full saturation and perched water throughout a significant volume of rock. Neither of these consequences has been observed beneath Yucca Mountain. Flow predominantly in fractures, therefore, would occur under models and scenarios that, though plausible--particularly under much wetter climates-are not considered likely.

Under such conditions, flow times through the small-conductivity units would become so short that they probably would contribute little to the total travel time from the repository to the water table. The flow time through the large-conductivity units probably would remain long, however, because flow in fractures would not be likely to occur in those units unless much larger fluxes occurred. In comparing locations on the basis of conditions that produce largely local flux, the thickness of the large-conductivity units is again the primarily surrogate.

Even though flow predominantly in fractures would shorten total ground-water travel times to the water table, geochemical retardation would still slow the movement of most radionuclides. This expectation is particularly likely for the large-conductivity units, where flow would probably still be in matrix pores. In the small-conductivity units, the predominance of flow in fractures might reduce the geochemical retardation, unless the contaminants diffuse effectively into the large-surface-area pores of the rock matrix. This matrix-diffusion process is expected to occur, but its effectiveness has not been well established. Under large-flux conditions, therefore, the retarding capacity of the small-conductivity zeolitic unit (CHnz) is questionable. For the purposes of this comparative evaluation of locations, the thickness of the large-conductivity units is used as the most reliable surrogate for retardation capacity, as well as for ground-water travel time.

In summary, the entire set of surrogate site characteristics is appropriate for evaluating locations under the flow conditions that probably exist at the Yucca Mountain site. Under less likely conditions of flow partly in fractures, the thickness of large-conductivity units, the total thickness of unsaturated materials, and the thickness of zeolitic units are the most useful surrogates. Under the even less likely conditions of flow predominantly in fractures throughout the small-conductivity units, the thickness of large-conductivity units is the primary surrogate.

Table 2 summarizes the preceding discussion. It lists 22 separate items considered for discriminating among performance potentials at alternative shaft locations and identifies seven as discrete surrogates for comparing the performance potential of the alternative shaft locations in the context of total site variability for each of the four NRC postclosure performance objectives in 10 CFR Part 60.112 and 60.113. Six of these are applicable to the undisturbed, nominal performance scenario category and are shown on the bottom of Figure 2. Only one other, overburden thickness, was identified to account for disturbed scenario categories. The following section compares these seven characteristics at the alternative shaft locations and discusses their implications for performance differences among these locations.

2.3 Comparison of Performance Potential at Alternative ESF Locations

2.3.1 Comparison of surrogate characteristics for postclosure performance across the Yucca Mountain site

Section 2.2 identified seven surrogate characteristics for comparing the postclosure performance potential of the five alternative shaft locations and the entire Yucca Mountain site. This section (1) establishes qualitative criteria for using each of the surrogates to compare potential performance across the entire Yucca Mountain site and at the five alternative shaft locations identified by Bertram (1984); (2) evaluates, for selected models and scenarios, the relative range of potential performance across the entire Yucca Mountain site and at the five locations; and (3) reviews the differences between the surrogates used in this report and the related screening criteria used by Bertram (1984). Sections 2.3.1.1 through 2.3.1.7 address each surrogate characteristic. Section 2.3.2 discusses the potential performance differences among the five alternative shaft locations in the context of the entire site in light of the combined effects of all surrogate characteristics.

2.3.1.1 Thickness of units with large and small saturated matrix hydraulic conductivity

Figure 3 shows isopach contours of the thickness of each of the hydrogeologic units that occur between the repository level and the water table. Figure 4 is a section along an approximate line of greatest thickness variations and provides a reference for interpreting the site-wide variations represented on Figure 3. Figure 5 shows a column of unsaturated hydrogeologic units at each of the five alternative shaft locations.

Table 2. Applicability of Surrogate Site Characteristics for Comparing Performance with Respect to NRC Performance Objectives (page 1 of 2)

	Containment 10 CFR 60.112	EBS releases 10 CFR 60.112	Ground-water travel time 10 CFR 60.112	Total system releases 10 CFR 60.11
<u>Nominal, Undisturbed Performance</u>	LLS	LLS	LLS	LLS
Hydrologic characteristics	LLS	LLS	LLS	LLS
Flux through unsaturated zone (UZ)	LLS	LLS	LLS	LLS
Downdip position of units	Yes	Yes	Yes*	Yes
Location of faults	Yes	Yes	Yes*	Yes
Surface topography	Yes	Yes	Yes*	Yes
Saturated hydraulic conductivity	LLS	LLS	LLS	LLS
Thickness of units	ND	ND	Yes*	Yes
Location of faults	Yes	Yes	Yes*	Yes
Thickness of underlying UZ	NA	NA	Yes*	Yes
Geochemical characteristics	ND	ND	NA	LLS
Water chemistry	ND	ND	NA	ND
Rock chemistry	ND	ND	NA	LLS
Thickness of underlying zeolites	ND	ND	NA	Yes
Thickness of underlying UZ	ND	ND	NA	Yes
Thermal-mechanical characteristics	ND	ND	LLS	ND
Distance to vitric units	ND	ND	II	ND
Distance to zeolitic units	ND	ND	II	ND
<u>Disturbed Scenario Categories</u>	LLS	LLS	NA	LLS
Direct releases, magmatic event	ID	ID	NA	ID
Engineered barrier partial failure	NSI	NSI	NA	NSI

Table 2. Applicability of Surrogate Site Characteristics for Comparing Performance with Respect to NRC Performance Objectives (page 2 of 2)

	Containment 10 CFR 60.112	EBS releases 10 CFR 60.112	Ground-water travel time 10 CFR 60.112	Total system releases 10 CFR 60.11
Increased flux above repository	LLS	LLS	NA	LLS
Depth to repository	Yes	Yes	NA	Yes
Surface topography	Yes	Yes	NA	Yes
Location of faults	Yes	Yes	NA	Yes
Downdip position of units	Yes	Yes	Yes*	Yes
Thickness of units	ND	ND	Yes*	Yes
Thickness of underlying zeolites	ND	ND	NA	Yes
Thickness of underlying UZ	ND	ND	NA	Yes
Water-table rise	NA	NA	NA	LLS
Thickness of underlying UZ	NA	NA	NA	Yes
Property changes in UZ	ND	ND	NA	ND
Appearance of new discharge points	NA	NA	NA	ND
Property changes in SZ	NA	NA	NA	ND
Direct releases, human intrusion	ND	ND	NA	ND

*Pre-waste-emplacement ground-water travel time is to be calculated along "fastest path" independent of shaft location.
LLS = lower level surrogate used for comparisons for this performance objective.
Yes = useful surrogate characteristics for comparisons (i.e., mappable and discriminating).
ND = nondiscriminating characteristic for performance according to current data.
NA = not applicable for this performance objective (i.e., unanticipated or no prewaste emplacement).
II = insufficient information about disturbed-zone definition to use as discriminator.
NSI = no scenario yet defined.
UZ = unsaturated zone; SZ = saturated zone.
ID = insufficient data for use as a discriminating factor.

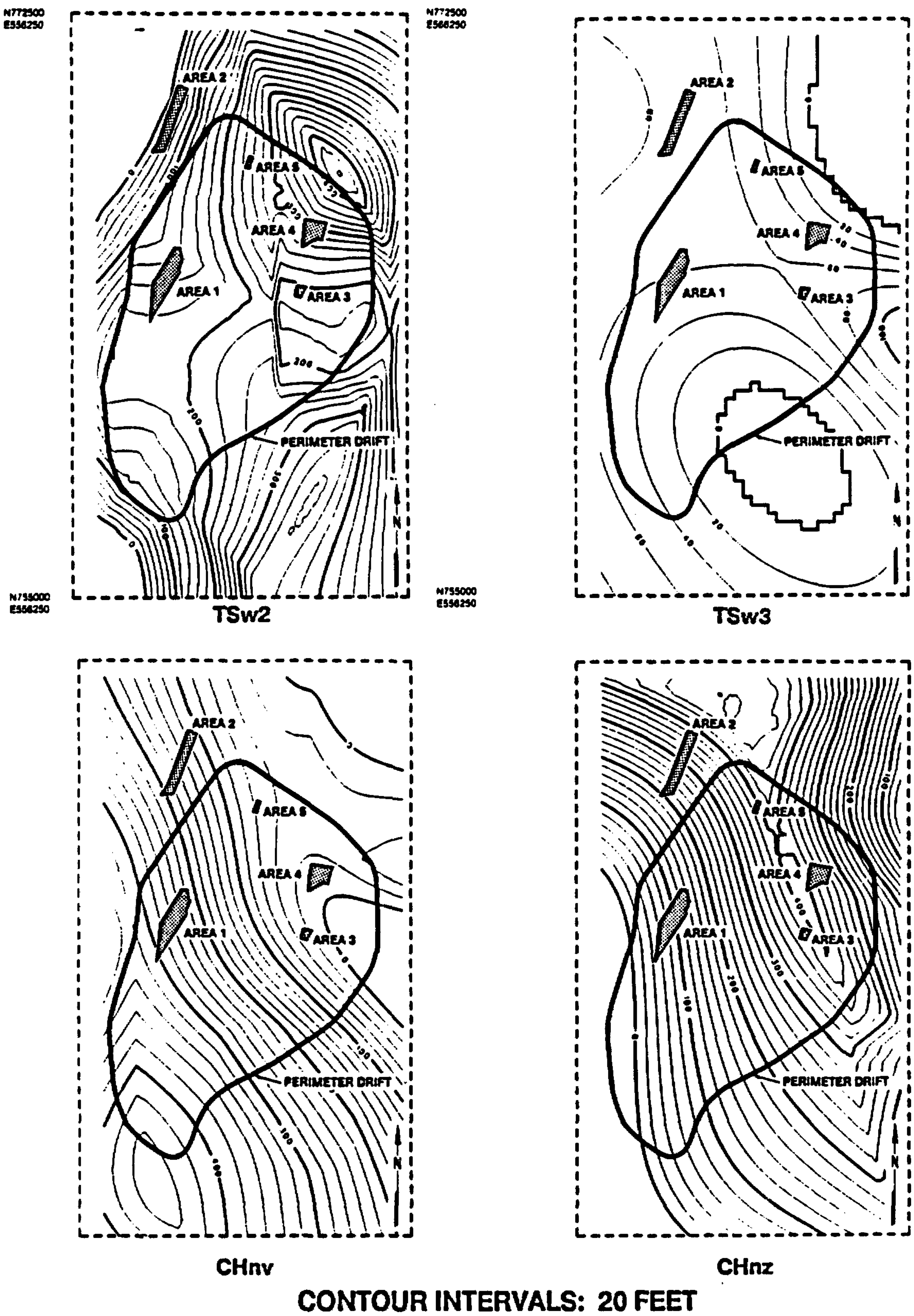


Figure 3. Isopach maps of hydrogeologic units between the repository floor and the water table.

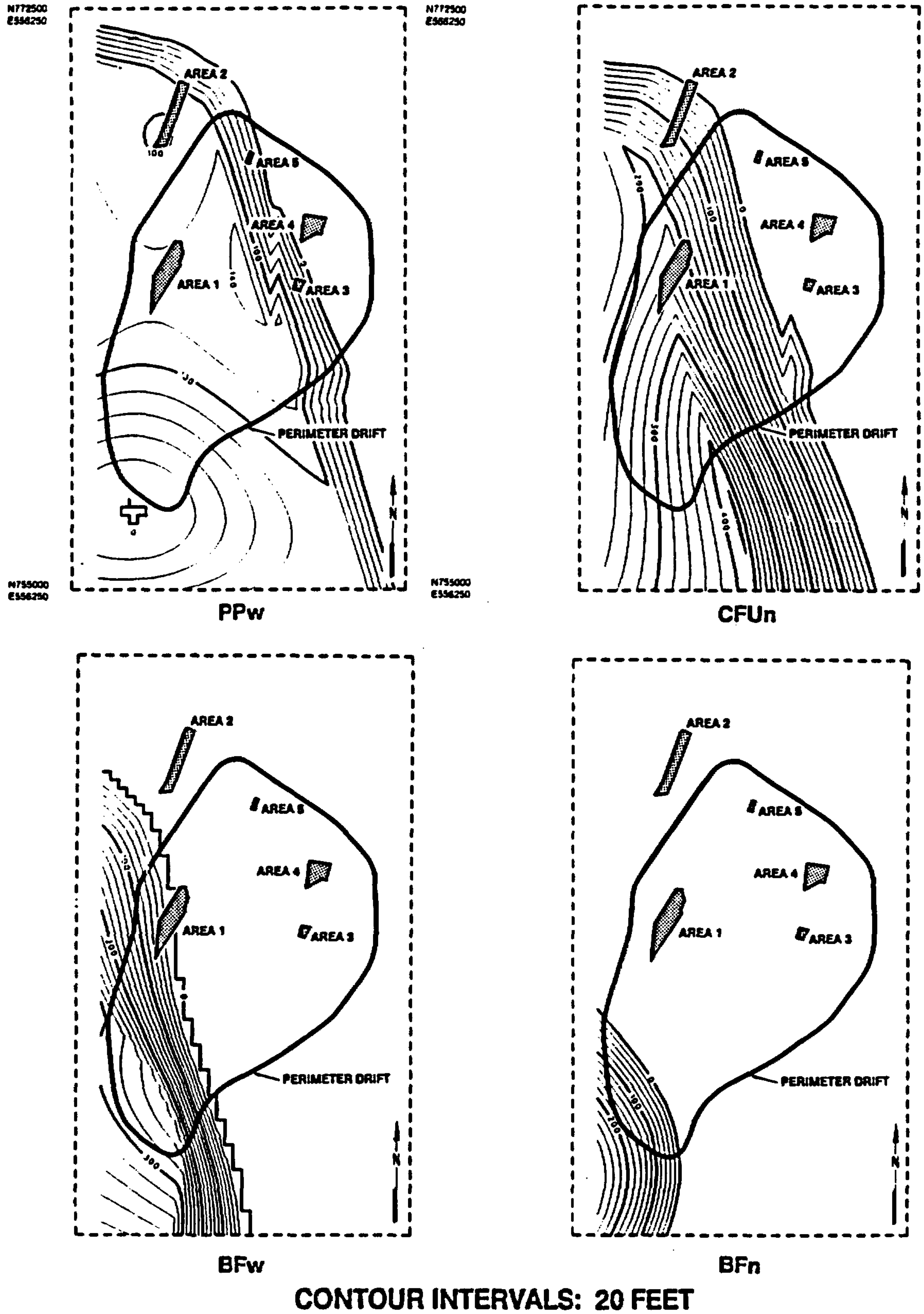


Figure 3. Isopach maps of hydrogeologic units between the repository floor and the water table. (continued)

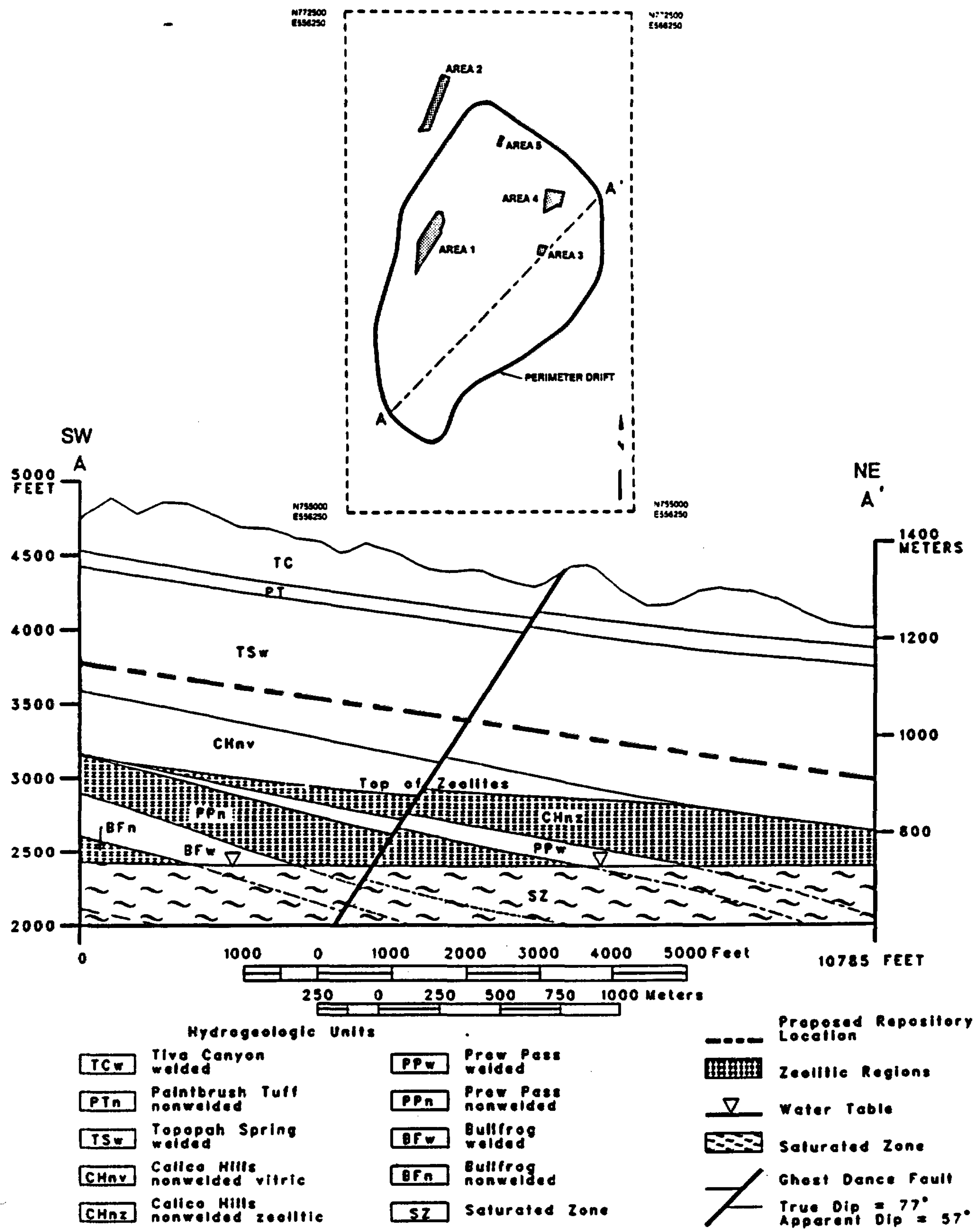


Figure 4. Southwest (SW) to northeast (NE) section of hydrogeologic units.

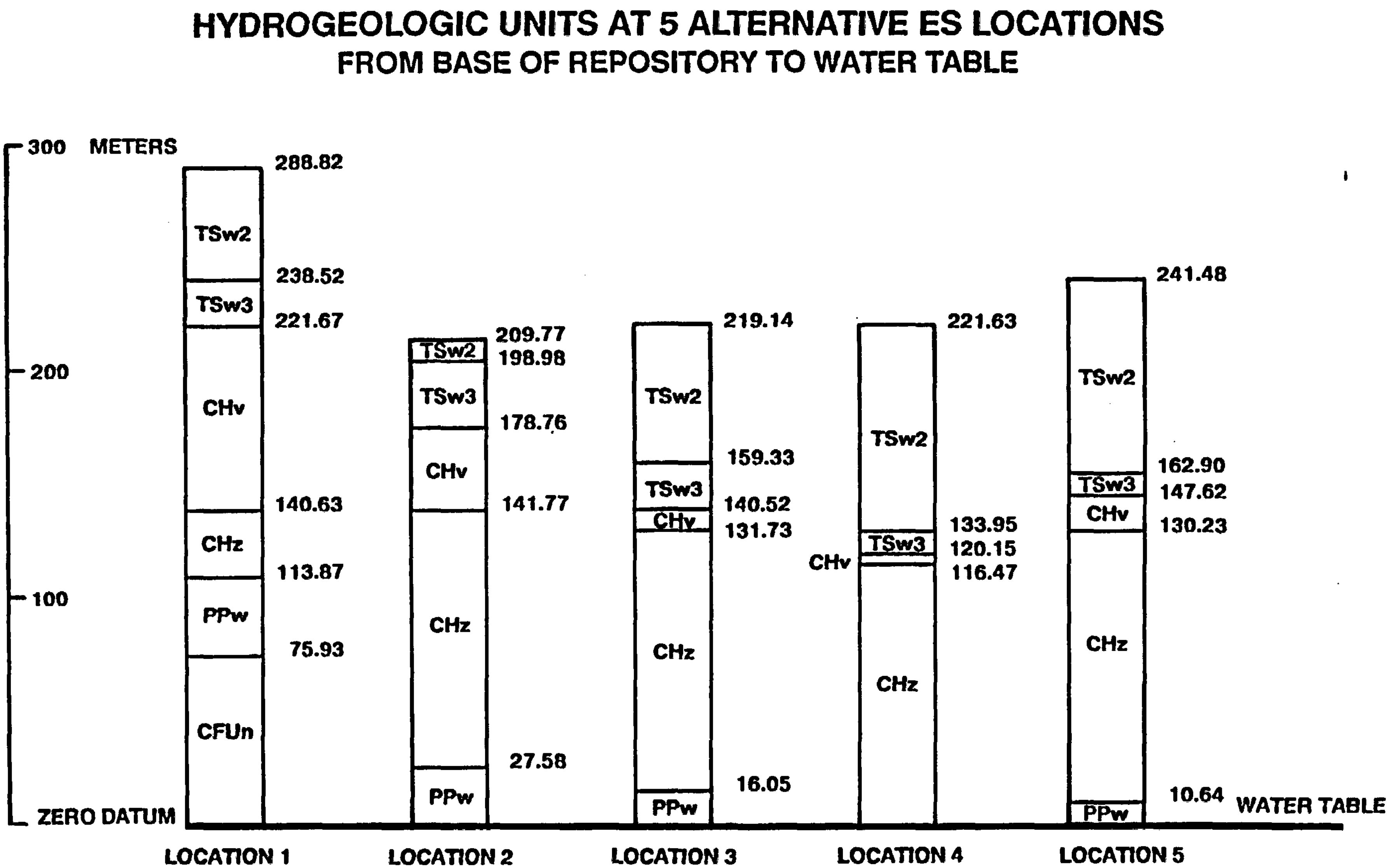


Figure 5. Hydrogeologic columns at five alternative shaft locations.

The following units are considered small conductivity units: TSw2, TSw3, CHnz, PPn, and BFn. TSw2 and TSw3 are densely welded and yield generally small conductivities, whereas CHnz, PPn, and BFn are nonwelded, but are assumed to be extensively zeolitic (Bish et al., 1984). This accounts for the assumed alteration of initially large conductivity rocks to small conductivity associated with zeolitization. Figure 6 shows the combined thickness of these small conductivity units.

The units that are considered to be characterized by large conductivity are CHnv, BFw, and PPw. The Chnv unit is nonwelded and occurs above zeolite interval II (Bish et al., 1984), the uppermost level of pervasive zeolitization of nonwelded units at Yucca Mountain. Limited data suggest this unit has a large conductivity characteristic of nonwelded, nonzeolitic tuffs. The PPw and BFw units, though moderately to densely welded in thin intervals within the mapped units, are predominantly devitrified and partially welded to nonwelded. Available data on conductivity and consideration of the model that nondensely welded, nonzeolitic tuffs have relatively large conductivities are the basis for classifying these units as large conductivity. Figure 6 shows the combined thickness of these large conductivity units.

Because, as discussed above, greater thickness of large conductivity units is associated with greater isolation potential, particularly for models or scenarios that include potential for flow in fractures, inspection of Figure 6 makes apparent the increasing isolation potential along a line extending approximately from the northeast corner of the site to the southwest corner. In effect, the isopach contours of Figure 6b could be interpreted as isoperformance contours under relatively large flux conditions.

The relative isolation potential of the five alternative shaft locations may be inferred from this surrogate characteristic as higher to lower performance potential in the following order: locations 1, 2, 5, 3, and 4. The greatest isolation potential based on this surrogate for large flux conditions would be provided by a location in the southwestern portion of the repository site (Figure 6b).

Bertram (1984) also identified thickness of units as a factor to consider in screening shaft locations, but only applied it after the five preferred locations were screened on the basis of other criteria. In addition, the thickness criterion was used by Bertram to rank the five preferred locations in terms of the thickness of the target repository host rock, rather than in terms of isolation potential related to thickness of variable rock types along the likely flow paths toward the accessible environment. The relation between thickness of the target host rock and scientific objectives was not explicitly defined by Bertram, but was related to construction objectives to "ensure the capability to mine subsurface facilities" (Bertram, 1984, page 55). Therefore, the consideration of unit thickness in this section augments the considerations of scientific objectives related to postclosure performance potential used by Bertram.

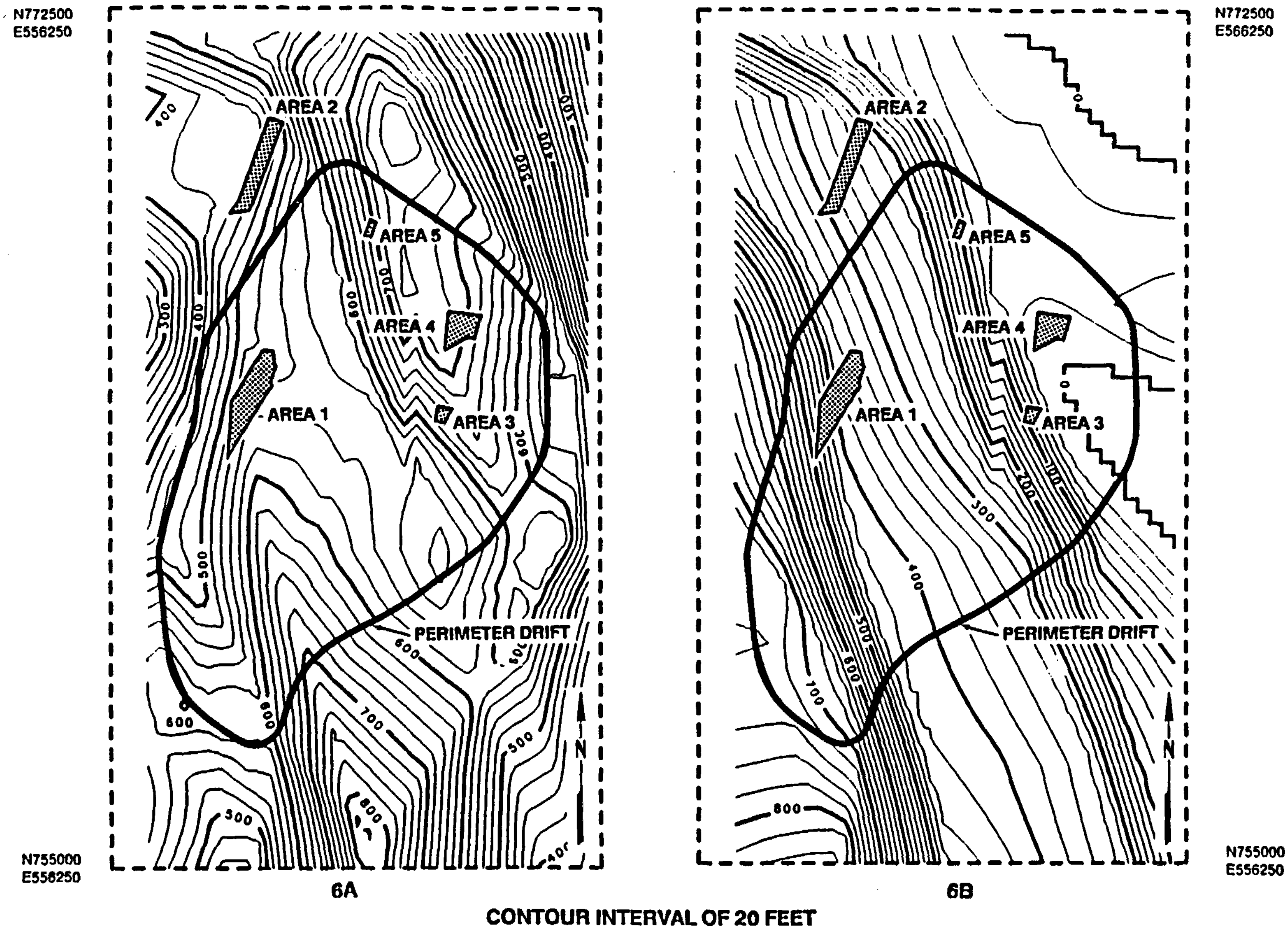


Figure 6. Combined thickness of small-conductivity units (Figure 6a) and large-conductivity units (Figure 6b).

2.3.1.2 Total thickness of unsaturated rocks beneath the repository level

Figure 7 shows the total thickness of unsaturated rocks beneath the current design elevations of the floors of the repository drifts (SNL, 1988). This is probably the dominant surrogate for postclosure performance if ground- water flow is primarily restricted, as expected, to the matrix pores of both large- and small-conductivity units. In this case, this characteristic is an appropriate surrogate for both ground-water flow and radionuclide retardation. Figure 7 shows that for matrix-dominated flow models and scenarios, the performance potential increases from the northeastern to the southwestern portions of the repository site. This is an identical pattern to that established above for thickness of large-conductivity units as a surrogate for performance under models or scenarios in which flow in fractures is predominant. Thus, independent of the details of the flow models or scenarios considered, a general trend of increasing performance potential toward the southwest is well established. The relative performance potential of the five alternative shaft locations based on this surrogate would range from greatest to least for, respectively, locations 1, 5, 4, 3, and 2, though the total range of the thicknesses is within about 30 percent of the thickness of location 1. The other surrogates discussed in the following sections establish local zones of potentially greater or lesser performance that are superposed on the general northeast-to-southwest trends established here and in the preceding section.

Bertram (1984) did not consider thickness of the unsaturated zone underlying the target repository horizons in the location-screening or ranking process for the preferred locations identified. Therefore, consideration of this characteristic augments the scientific considerations related to postclosure performance addressed by Bertram.

2.3.1.3 Locations of faults that may serve as conduits for vertical flow

Figure 8 shows the locations of fault traces along the surface throughout the area considered in this report. This figure represents a current, essentially unchanged, version of the fault map used by Bertram (1984, page 62) to exclude from consideration all locations within 100 feet (setbacks) from these faults.

In revisiting this surrogate characteristic, objectives discussed by Bertram on page 56 of the report seem generally applicable. Though Bertram did not establish the relation between the potentially adverse structures and postclosure performance, the map on Figure 4 of their report seems appropriate to use as a basis for identifying the likely areas where flux concentrations, due to lateral diversion, may vertically drain into the water table. An exception to this occurs south of the line 4000 feet north of borehole USW H-3, where additional areas more than 100 feet from potential fault conduits occur. Assuming performance would be less favorable (though not necessarily unacceptable) in these potential conduits, Figure 4 of Bertram (1984), extended to the south, can be used to identify two types of zones: higher-performance zones (shaded areas on Figure 4 of Bertram) and lower-performance zones (blank areas within the outline of the exploration block on Figure 4 of Bertram). Thus, consideration in this report of fault locations as a surrogate for performance essentially adopts the use of the same characteristic by Bertram. However, in this report, only the map of

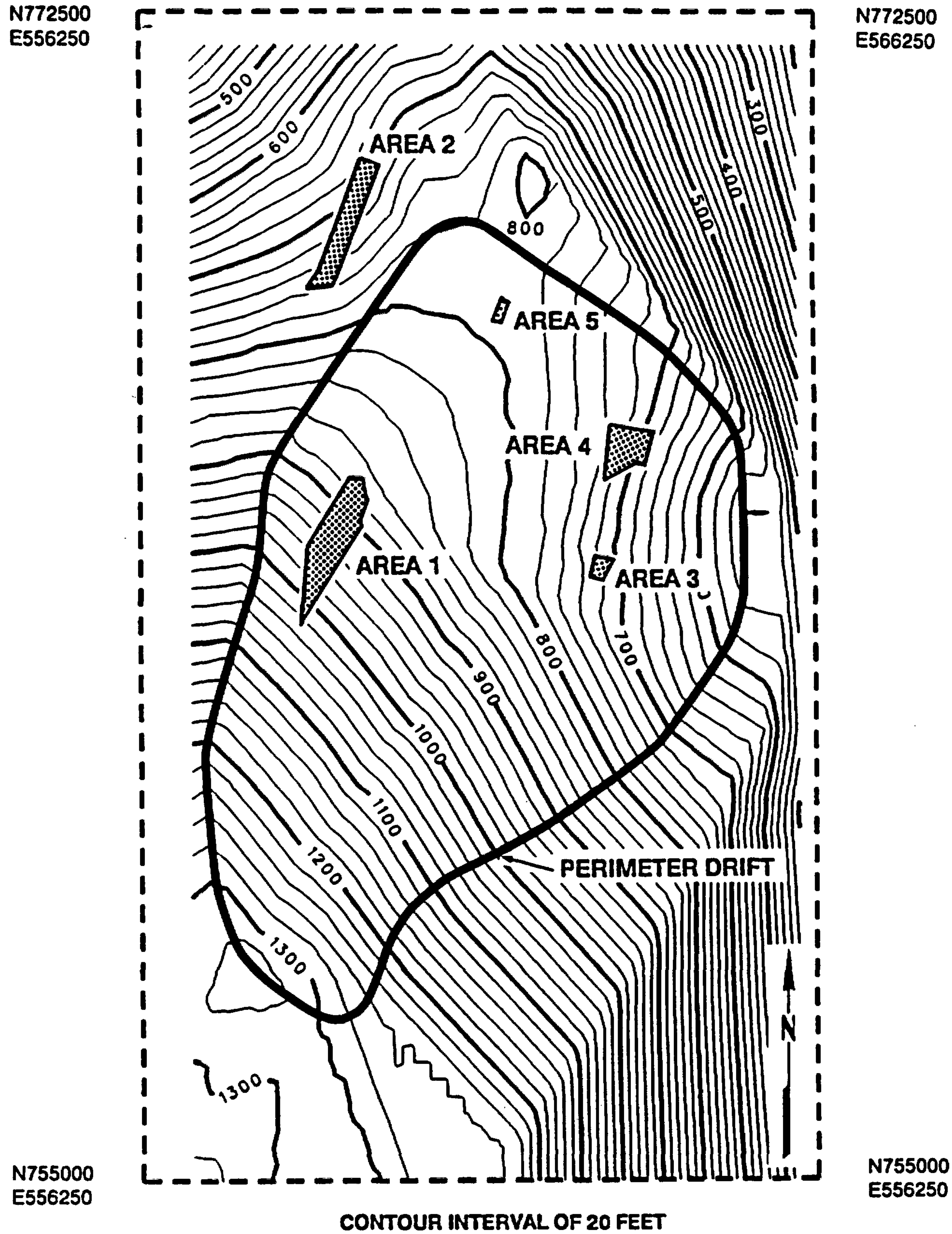


Figure 7. Total thickness of unsaturated rocks beneath the repository; hypothetical elevation of repository floor extended to edge of map area.

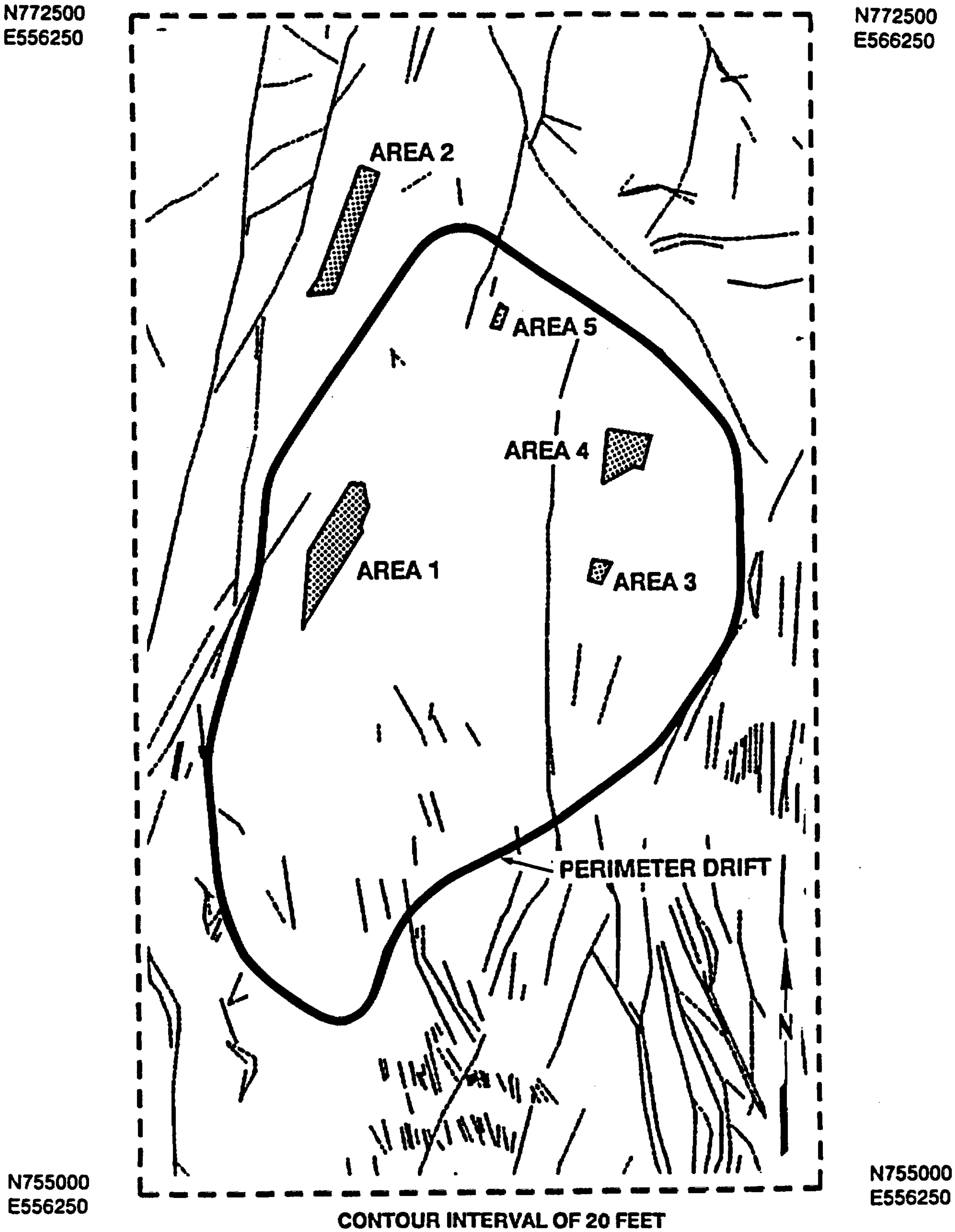


Figure 8. Location of surface traces of faults within the repository area.

100-foot setbacks is used and the area of consideration is extended south of the limit used by Bertram. Because Bertram (1984) excluded all areas within 100 feet of faults, all five alternative locations compared by Bertram are in an acceptable zone.

2.3.1.4 Topography as a determinant of potential zones of surface-infiltration concentrations

Figure 9 shows the generalized topography in the Yucca Mountain area. As discussed in Section 2.2.1, topography may influence the infiltration patterns at Yucca Mountain. These, in turn, may influence the spatial distribution of flux at the repository depths and below, along flow paths toward the water table and, therefore, toward the accessible environment. According to one conceptual model, concentrations of infiltration are more likely to occur in the areas of flatter terrain, such as that along ridge crests, in drainage channels, or in localized depressions. This model states that infiltration and underlying flux concentrations are most likely to occur along drainage channels, where surface runoff is concentrated during intense, but rare, rainstorms. Less likely, though plausible, are concentrations of infiltration from snowmelt and gentler rain along the relatively flat ridge crests or perhaps even canyon slopes where bedrock fractures are directly exposed. Other factors, such as the distribution of precipitation and characteristics of surficial deposits, also influence infiltration. An alternative model states that infiltration is not significantly affected by topography. Much field and interpretive work is planned to estimate the infiltration distribution across the site, evaluate the controls on this distribution, and establish the relation between infiltration and flux distribution at the repository level and below (DOE, 1988, Section 8.3.1.2.3). For the purposes of this report, it is assumed that three types of potential flux environments occur at Yucca Mountain:

1. Largest flux along lower reaches of drainage channels.

2. Intermediate flux along relatively flat ridge crests, upper reaches of drainage channels, and in localized depressions.

3. Smallest flux along slopes of canyon walls.

Where the flux is likely to be smaller, the performance potential is likely to be greater; therefore, environments 1 through 3 represent likely regions of successively better performance. As a result, the relative performance potential of the five shaft locations may be classified in terms of this surrogate characteristic as follows: locations 1 and 2, along Yucca Crest, with relatively high isolation potential; locations 3, 4, and 5, along lower reaches of drainage channels, with relatively low potential. Because of the currently large uncertainty about the flux distribution and its causes, the relative magnitude of potential flux differences (and even their existence) can not be estimated with any confidence at this time. Therefore, this surrogate characteristic for performance should not be considered as a definitive indicator of performance potential.

Bertram (1984) used topography as a screening attribute because construction would be more difficult in regions of adverse topography (steep slopes). Bertram also used the potential for flash flooding (a consequence

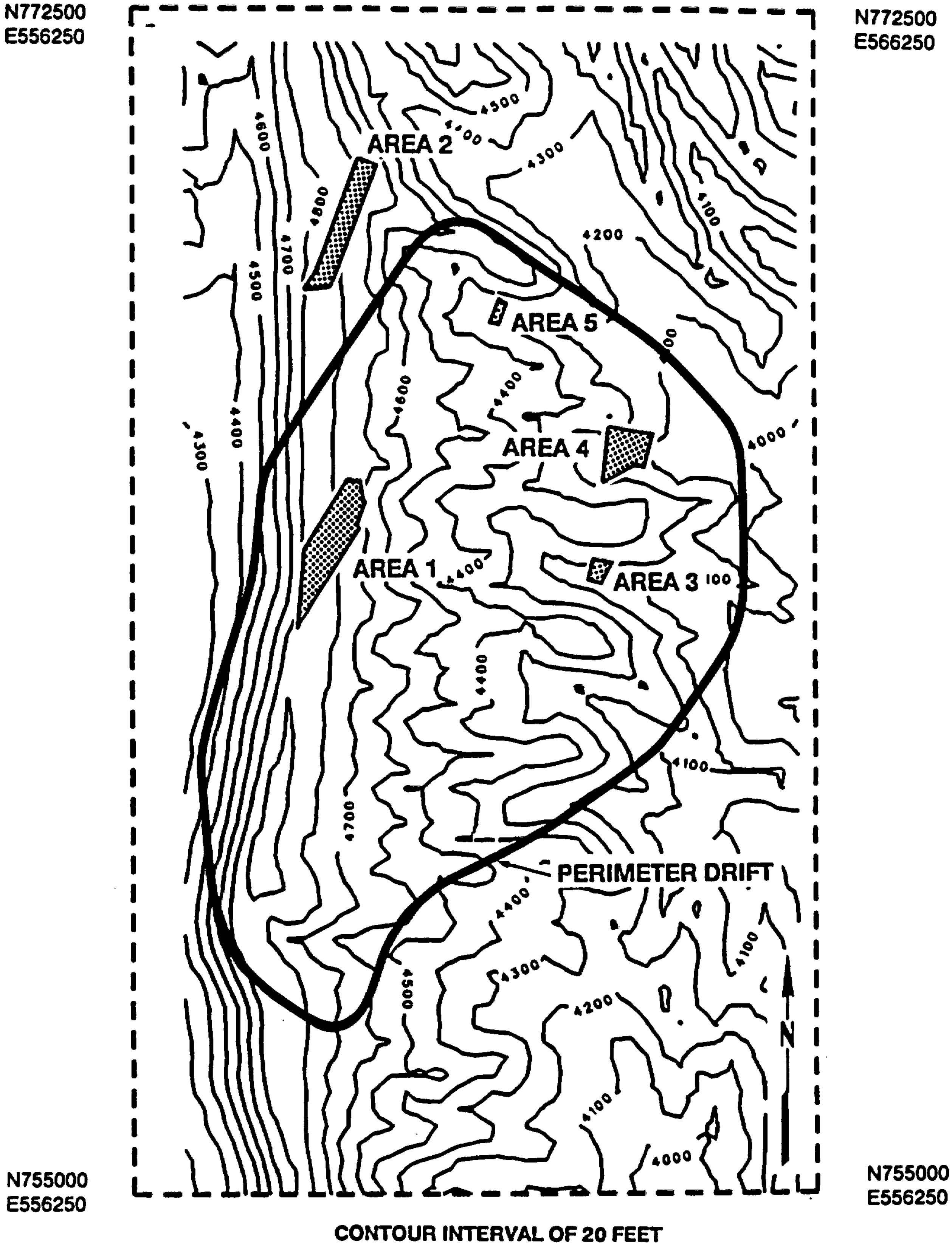


Figure 9. Topography of the Yucca Mountain area.

of topography) as a basis for comparing the engineering attributes of the five locations following the site-wide screening. The screening process did not consider any potential effects of topography, including flood potential, on isolation capabilities of the alternative locations at Yucca Mountain. Therefore, the areas of relatively flat terrain, a characteristic considered favorable in the Bertram report, are considered relatively less favorable for isolation potential in this evaluation. The areas of higher flood potential are considered less favorable in both the Bertram report and this evaluation, but for different reasons.

2.3.1.5 Distance downdip as an influence on subsurface concentration of flux

Figure 10 shows the structure contours at the base of the Topopah Springs welded unit. The contours show the altitudes of the base of the unit and can be interpreted to estimate the general direction and magnitude of dip of the hydrostratigraphic units in the repository area. Though other units dip slightly differently from the pattern shown on Figure 10, the variations are slight, and this map is sufficiently representative that it may be used to compare locations in the Yucca Mountain area with respect to dip of hydrostratigraphic units. As discussed in Section 2.2.1, the downdip position of any place within the repository may be used to infer the distance across which downdip, lateral diversion of flux has occurred. The greater the distance, the greater is the potential for build-up or concentration of flux that is then available for vertical percolation. Therefore, the potential for larger flux values becomes more likely as the distance downdip increases. If faults serve as conduits to drain the laterally diverted flux, then the areas downdip from, but adjacent to, the faults may have the smallest flux values. Whether lateral diversion occurs and where the diverted water would resume vertical drainage are complex questions whose answers depend on many factors, including the magnitude of the flux, the saturation of the rocks, the magnitude and variability of permeability within and between rock types, the hydrologic characteristics of faults, and other characteristics.

In lieu of data that will be gathered during site characterization to address this phenomenon, it is assumed for this comparison that the potential for larger flux through and below the repository level increases downdip (generally eastward) from the Solitario Canyon Fault to the fault zone bounding the repository area on the east. Performance potential is therefore assumed to decrease toward the east. Though the Ghost Dance Fault may act as a vertical conduit to intercept any laterally diverted flux, it is not treated as such here. Therefore, the increase in distance downdip and the corresponding decrease in performance potential are as follows: locations at (updip, higher performance potential), 1, 2, 5, 3, and 4 (downdip, lower performance potential).

2.3.1.6 Thickness of zeolites in the unsaturated zone

Figure 11 shows isopachs representing the total thickness of unsaturated units classified by Bish et al. (1984) as composed predominantly of zeolite minerals. All these units occur below the repository level. As discussed in Section 2.2.2, zeolites may provide greater retardation of radionuclide transport than nonzeolitic units. Therefore, performance potential probably correlates with the thickness of the zeolitic units and accordingly increases

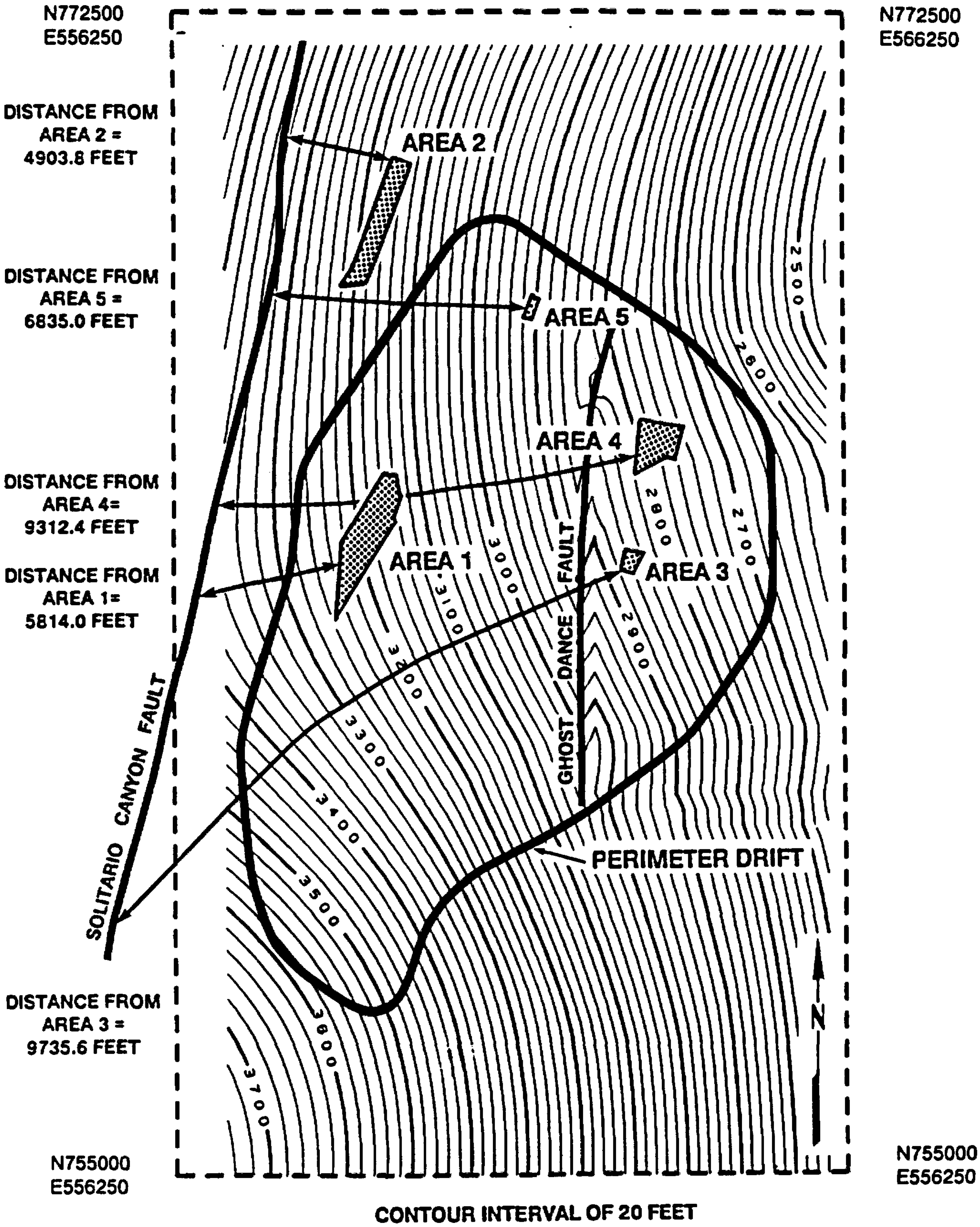


Figure 10. Structure contour map of the base of Unit TSw3 with distances from areas to Solitario Canyon Fault.

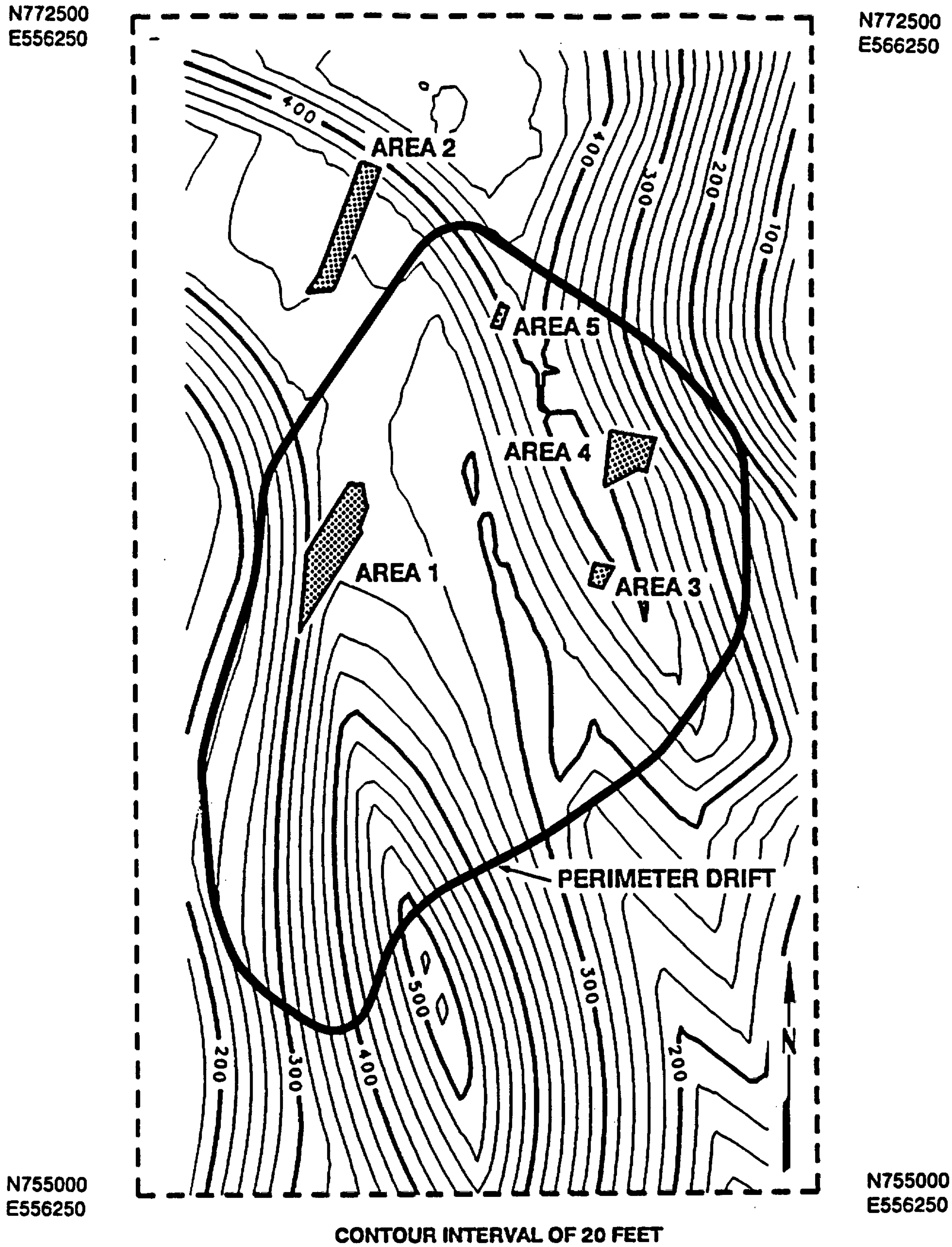


Figure 11. Isopach map of the total thickness of zeolitic units between the repository level and the water table.

with respect to this surrogate from the southwest portion of the site to the northeast. The five preferred locations identified by Bertram (1984) range from potentially better to poorer performance (for this surrogate), respectively, as follows: locations 5, 4, 3, 2, and 1, though total differences are within 10% of the largest volume of zeolite thickness.

2.3.1.7 Thickness of overburden

Figure 12 shows isopach contours of the thickness of overburden above the drift floors of the current repository design. As discussed in Section 2.2.4.4, this site attribute serves as a surrogate for performance under scenarios of increased infiltration and associated flux due to climatic change. The thicker the overburden, the longer the time for any increased flux to percolate down to the repository level, where it may contact and corrode the waste canisters, eventually breaching them, dissolving the waste, and transporting radionuclides. Therefore, the areas of greatest overburden thickness are the areas of potentially better performance under increased flux scenarios. Accordingly, the five alternative locations of Bertram (1984) range from higher to lower performance potential with respect to this surrogate in two groups, as follows: locations 1, 5, 4, 3, and 2, though the total variation is less than 30% of the greatest overburden thickness.

2.3.2 Summary of comparisons of postclosure performance potential of alternative shaft locations

2.3.2.1 Comparison of five alternative locations identified by Bertram (1984); TAR Part II - Element 1

Table 3 summarizes the relative ranking of the five alternative shaft locations in terms of the seven surrogates for postclosure performance discussed in Section 2.3.1. The ranking values for the surrogates indicate that locations 1, 2, and 5 generally have the greater potential for more favorable performance, while locations 4 and 5 have a lesser performance potential. If only the surrogates concerned primarily with hydrologic behavior are considered (the first five surrogates in the list in Table 3), then the differences among the locations are accentuated. In this case location 1 and 2 are considerably higher ranked than locations 3, 4, and 5. In either case, location 4, the current shaft site in Coyote Wash, ranks lowest of all five sites.

These rankings are not intended as indicators of proportional differences in performance among the locations. Rather, they may be construed to represent the relative influence of multiple natural barriers that may occur at the locations. Under expected, nominal conditions, all locations are likely to isolate wastes much longer than is required by regulations, so the relative differences among them may reasonably be considered insignificant. It is only under conditions represented by disturbed scenarios or alternative conceptual models of hydrologic behavior that differences among the locations are potentially significant in terms of compliance with regulations. Even if a particular location within the repository, as represented by the alternative shaft locations, fails to provide ground-water or radionuclide travel times of 10,000 years, this does

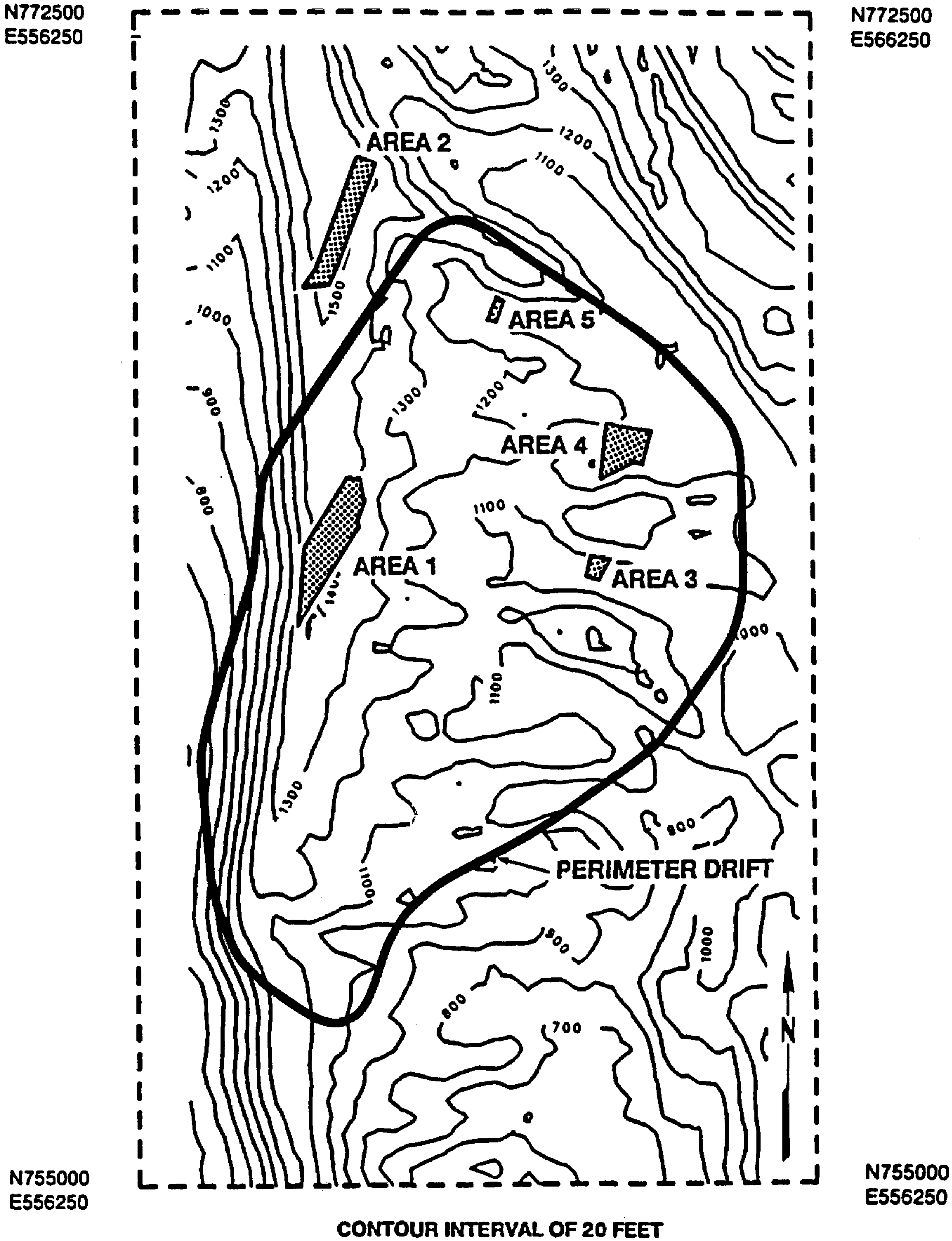


Figure 12. Isopach map of the total thickness of repository overburden; hypothetical elevation of repository floor extended to edge of map area.

Table 3. Relative ranking of each alternative shaft location with respect to surrogate site characteristics for postclosure performance

SURROGATES	Location 1		Location 2		Location 3		Location 4		Location 5	
	Value	Rank[a]	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Thickness of large-conductivity units (ft)	395	1	205	2	81	4	12	5	91	3
Thickness of unsaturated zone below repository (ft)	948	1	688	3[b]	719	3[b]	727	3[b]	792	2
Location of faults[c]	Zone 1	1	Zone 1	1	Zone 1	1	Zone 1	1	Zone 1	1
Topography[d]	Zone 2	2	Zone 2	2	Zone 1	3	Zone 1	3	Zone 1	3
Distance downdip[e] (ft)	5814	2	4904	1	9736	4[b]	9312	4[b]	6835	3
Thickness of zeolites (ft)	332	2	374	1[b]	380	1[b]	382	1[b]	392	1[b]
Thickness of overburden (ft)	948	1	688	3[b]	719	3[b]	727	3[b]	792	2

[a]Lower rank values correspond to greater isolation potential, higher rank values to lesser isolation potential.
[b]Insufficient differences for discrimination; value at a site less than 10% above lowest value in a group of same ranking.
[c]Two zones possible: Zone 1, greater than 100 feet; Zone 2, less than 100 feet.
[d]Three zones possible: Zone 1 - drainage channels; Zone 2 - ridge crests; Zone 3 - steep slopes.
[e]Distance from Solitario Canyon fault to location along contact at base of TSw3.

not mean that the site as a whole, in conjunction with engineered barriers, will also fail to meet regulatory requirements.

For example, scenarios of flow predominantly in fractures require a local flux substantially greater than current estimates of the average flux across the site. If the cause of the locally large flux is lateral diversion in the subsurface, then large portions of the repository area would be characterized by even smaller flux values than the average. For these regions, travel times would be longer than those in the areas of locally large flux. Also, any regions of flux concentrations are expected to be detected during site characterization and avoided as regions of waste emplacement. Thus, the scenarios of localized, rapid flow in fractures could even be advantageous by providing conditions that would "divert downward moving water to a location beyond the limits" of waste-emplacement areas, thereby meeting the spirit of the siting criterion for favorable conditions in 10 CFR Part 60.122(b)(8)(iii).

In summary, the results of this comparative evaluation of alternative shaft locations should be interpreted with utmost caution in terms of the potential for the overall Yucca Mountain Mined Geologic System to meet regulatory requirements. This comparison is intended only to establish any likely differences in isolation potential among the alternative shaft locations, not to estimate the potential for any of the locations or, particularly, the site as a whole to meet regulatory requirements. Differences were found among the locations, though these differences are significant only under disturbed scenarios or hydrologic models that predict local concentrations of flux, which, as discussed above, can be detected and avoided for waste emplacement. In general, this comparison indicates that the locations on the ridge crest to the west (locations 1 and 2) and, especially, the southwest (location 1) tend to have characteristics that are more favorable for isolation than locations in the washes to the east and northeast (locations 3, 4, and 5).

2.3.2.2 Comparison of performance potential across the entire site; TAR Part II - Element 3

The trends of improving performance that are indicated for the five alternative locations considered by Bertram (1984), appear to continue to the southwest, suggesting that locations with the best performance potential occur in the southwestern corner of the repository area, where the unsaturated zone beneath the repository is thickest and characterized almost exclusively by large conductivity, nonwelded or partially welded, nonzeolitic tuffs. Similarly, locations with the least performance potential probably occur toward the northeast where densely welded and zeolitic, small-conductivity units dominate the unsaturated stratigraphic section beneath the repository. This general northeast-to-southwest trend of improving performance caused by hydrostatigraphic geometry may be accentuated by structural and topographic patterns that could increase the likelihood of, respectively, vertical drainage of downdip lateral diversion and infiltration pulses due to storm runoff toward the northeast. These conditions, in turn, could result in greater liklelihood of local concentrations of flux and associated zones of shorter flowtimes toward the northeast.

The five alternative locations considered by Bertram (1984) therefore encompass a limited range of the potential performance differences across the entire Yucca Mountain site. The lower end of the range is well represented by the five alternative locations, but the upper portion of the total range is only represented by location 1, which is just far enough to the south to begin to represent the upper range of site performance. The full range of site performance probably would have been encompassed by alternative shaft locations if Bertram (1984) had not excluded areas south of a line 4000 feet north of USW H-3. This probably includes the areas where the most favorable site characteristics are likely to occur.

2.4 Implications of potential performance differences for shaft siting

Section 2.3 provides the basis for establishing a range of potential isolation capabilities across the Yucca Mountain site. How should these differences be used to help identify the preferred location for an exploratory shaft? The answer to this question depends on several factors, including:

- the magnitude of the differences;
- the degree to which the worst or best performing locations could jeopardize compliance of the overall site with regulatory requirements;
- the conditions that might lead to such jeopardy;
- the likelihood of such conditions at alternative locations;
- the ability to characterize these conditions from the shaft; and
- whether construction or operation of the shaft facilities could cause an otherwise acceptable site to fail to meet the regulatory requirements.

An important consideration in evaluating alternative ESF locations is the overall estimates of postclosure performance with respect to the regulatory requirements, particularly those discussed in 10 CFR Part 60, Subpart E (60.112 and 60.113). The DOE has discussed evaluations of the overall site performance in the environmental assessment (EA) (DOE, 1986a) and supporting references (Sinnock et al. 1984), and in the decision-methodology document (DOE, 1986b), which was used to select candidate locations for site characterization. Each of these discussions concluded that, on the basis of existing information, the overall site performance was thought to meet the regulatory requirements and to exceed them by orders of magnitude. The following discussion summarizes these evaluations.

Section 6.4.2 of the EA summarizes a prediction, based on available data, of postclosure site performance. Site performance was calculated for an expected case, which was intended to be a highly conservative underestimate of the performance, and, in order to address uncertainties, a performance-limits case. In addition, the results of Sinnock et al. (1984)

were available, and were used to reach many of the conclusions discussed in the EA. Sinnock et al. (1984) reported on analysis and sensitivity studies to address such factors as ground-water flow time, waste dissolution rate, and releases to the accessible environment (considering both expected conditions and unlikely conditions). The conclusions of the EA and Sinnock et al. (1984) are consistent and are summarized as follows: For expected conditions, calculations indicate that no wastes would move the several hundred meters from the repository to the water table in 10,000 years. It is likely that no wastes would arrive at the water table for hundreds of thousands of years, and then only insignificant hazards would be posed by the remaining radioactive material. For certain combinations of unlikely conditions, each condition itself unlikely, scenarios could be postulated that would result in significant releases. However, the probabilities of these scenarios were expected to be so unlikely that the site would meet the requirements by several orders of magnitude. The primary uncertainty that was unresolved was the overall hydrologic flow processes operating at the site. Recent calculations by Dudley et al. (1988) support these general conclusions.

The above conclusion was also reached by a panel of experts as part of the selection of candidate sites for characterization as part of the DOE's decision-aiding methodology (DOE, 1986b). Chapter 3 of the methodology document concludes, for the Yucca Mountain site, that there is high confidence that the site performance is several orders of magnitude below the EPA standard. The judgments that were made included evaluations of both unlikely conditions and potential disruptive scenarios and included sensitivity and uncertainty analysis as part of determining the overall confidence in conclusions.

Although the performance of the site is expected to meet the regulatory requirements, many uncertainties are recognized, particularly those due to a lack of hydrologic process data and understanding. Recent effort has concentrated on identifying the key uncertainties associated with site performance. One example of this effort was the development of tables describing alternative conceptual models for the site characterization plan (DOE, 1988, Section 8.3.1). The purpose of these tables was to identify the full range of reasonable alternatives compatible with existing knowledge, so that site characterization would produce data that would help to narrow the range of alternatives, thus adding to confidence in the understanding of site performance. Thus, the decision regarding the alternative shaft locations must consider both the expected conditions (thought to be very favorable), and the current uncertainties in factors such as alternative conceptual models, unexpected conditions, and potential disruptive scenarios.

This section provides the basis for a conclusion, based on the first six factors itemized at the beginning of this section, that the location in Coyote Wash (location 4) is the preferred location. Section 3 follows and addresses the last factor.

The differences among the shaft locations identified in Section 2.3 may be relatively or absolutely either small or large, depending on (1) the proper hydrologic model that characterizes the current flow system in the unsaturated zone, and (2) the likelihood of various disruptive scenarios that might locally or pervasively increase flux through the repository level and below. Under current assumptions about expected nominal conditions and models, the differences among the locations are relatively large, but they probably are not significant, because absolute performance at all locations would probably be much greater than regulatory requirements. No evidence exists to indicate that any of the shaft locations possess conditions that would cause the site to fail to meet regulatory requirements. If such evidence existed, it would have led to a recommendation not to proceed with site characterization at Yucca Mountain, at least not under the current design for the repository location.

On the other hand, current evidence is not reliable or extensive enough to definitively rule out the possibility of certain conditions, models, or scenarios that could lead to failure to comply with regulations. Such conditions, though currently believed to be unlikely or restricted in area, include concentrations of flux that result in rapid flow through fractures from the repository level to the water table. Such flux concentrations, if they occur, would cause local saturations to be large and capillary pressures to be small. These conditions will be tested from the exploratory shaft facilities. Such conditions, though not expected pervasively at any of the shaft locations, are more likely to occur in the eastern and northeastern portions of the Yucca Mountain site, including the shaft location in Coyote Wash and perhaps the nearby structures targeted for exploration by the drifts of the shaft facilities. These potentially unfavorable conditions are not currently considered probable enough to make the Yucca Mountain site unsuitable. Because they are most likely to occur, if at all, in the region targeted for exploration by the currently designed shaft facilities, it is prudent to place the shaft in Coyote Wash. A primary purpose of the exploratory shaft is exploration for conditions that might cause the site to fail to meet regulatory objectives. The Coyote Wash location is an opportune location for fulfilling that purpose because it is in the general region of less favorable, but testable, performance.

Thus, if the process reported by Bertram (1984) had explicitly considered waste-isolation performance potential in the evaluation of alternative shaft locations, the basis for the selection of the Coyote Wash location probably would have been strengthened. This conclusion also rests on the evaluation in the next chapter, which establishes that the construction of the shaft should not render the site unsuitable.

3 The Effect of an Exploratory Shaft Facility at Each Location

After the two exploratory shafts have been sunk, an extensive set of tests will be carried out in one of them and in excavations made from them. These tests will be an important part of the site characterization activities that will lead to an evaluation of the suitability of the Yucca Mountain site for development as a repository. The shafts and the additional excavations are known collectively as the exploratory shaft facility (ESF). The Yucca Mountain Site Characterization Plan (SCP) (DOE, 1988) describes in detail the ESF and the tests to be carried out in it.

Chapter 2 of this report compares the waste isolation capabilities of the five alternative locations for exploratory shafts. This chapter reports an examination of the effects that an ESF would have at those locations; the DOE has done this examination in compliance with the preapplication review requirements of 10 CFR Part 60, paragraphs 60.15(d)(1) and 60.17(a)(2)(iii and iv). Such effects were not an explicit part of the criteria used in selecting the locations (Bertram, 1984). This section reviews the available information on these effects and suggests how such information might have affected the selection if it had been an explicit part of the selection process.

3.1 Summary of Effects

The construction of the ESF and the tests performed in it must not, according to 10 CFR Part 60.15(d)(1), make the site unsuitable for use as a repository. In other words, they must not result in a loss of waste isolation capability. To evaluate whether the ESF meets this criterion, the DOE has conducted analyses that examine the effects of the ESF on waste isolation. These analyses, which also deal with the effects of other site characterization activities, are reported in Section 8.4.3 of the SCP.

These analyses are appropriate for the purposes of this report (i.e., deciding how studies of the effects of shafts might have affected the selection of an exploratory shaft location). The following discussion summarizes the material in the SCP and refers to specific sections where the more detailed discussions appear. A reader who wishes a more complete understanding of the analyses will need to consult the SCP. A full understanding will also require study of the references cited there.

3.1.1 Supporting analyses and data

Section 8.4.3.2 of the SCP begins the study of effects of an ESF by summarizing the technical analyses and data that support the further studies of the effects. These analyses deal with potential changes to three general sets of properties of the site: hydrologic conditions, geochemical conditions, and the thermal and mechanical properties of the rock. Because site characterization has not yet begun, all the analyses use preliminary data and simplified conceptualizations of the physical processes operating in the unsaturated zone at the site. In general, the analyses apply equally well to any of the five alternative shaft locations identified in the Bertram report.

Analyses of changes to hydrologic conditions

The DOE has made numerous analyses to examine water infiltration from the surface, ground-water flow in matrix and fractures, redistribution of water retained in the unsaturated zone, and the movement of water vapor. Section 8.4.3.2.1 of the SCP cites several analyses dealing with each of these topics. The analyses are useful in estimating the effects of an exploratory shaft, because they describe how far water, introduced during site characterization, might penetrate the rock formations, what the changes in hydrologic conditions might be, how long these changes might take to occur, and how long they might persist. They are particularly useful in estimating the three most important types of potential hydrologic effects: changes in the amount or distribution of ground-water flux, changes in the distribution of hydrologic properties, and the creation of preferential pathways. Such changes might adversely affect the waste isolation capability of the site if they were widespread or substantial.

In support of the preparation of this report, independent reviews were made of the conclusions drawn in Section 8.4.3 of the SCP regarding the hydrologic effects of an ESF; the reviews included detailed examinations of analyses performed by Fernandez et al. (1988) and West (1988), upon which some important conclusions are drawn. Detailed results of those reviews are included in Appendix K of the review record memorandum to which this report is also an appendix. Various technical points were raised by the reviewers regarding possible alternative or additional analyses that could have been made by Fernandez et al.; some of these could affect shaft design. For example, one reviewer (Trautz, Appendix K2) concluded that Fernandez et al. may not have taken a sufficiently conservative approach to estimating the draft pressures needed to calculate the conductivity of the backfill material in the shaft that is required to minimize convective air flow. These design aspects are considered in the assessment carried out as part I of the technical assessment of Title I design and are reported in Chapter 3 of the review record memorandum.

In a review of West (1988), Doty (Appendix K4) noted that West's conclusion of a value of 10 percent may underestimate the average amount of drilling fluid that is expected to be lost to the surrounding rock mass as a result of shaft excavation and drifting. In agreement with the analyses in SCP Section 8.4.3, Doty's review also notes that the distance that drilling fluids travel in a fracture network depends on the imposed boundary head and the hydraulic properties of the fractures. Because these properties are largely unknown for the fracture networks at Yucca Mountain, uncertainties exist about the distance that water would move. West's conclusion that the water would not penetrate very far is based on various analyses that included a range of conditions and takes into account the conservative water use practices that are expected to be used. Thus, concerns about the extent of penetration and the loss of various fluids may be compensated for by the planned use of dry-mining and minimal water-mining techniques, where appropriate, and by the planned restrictions on the use of hydrocarbons and solvents.

In general, the reviewers came to the following conclusions: (1) the conceptual and numerical models used were appropriate; (2) the assumptions were conservative; (3) the boundary conditions and data inputs were reasonable;-and (4) the conclusions that were drawn were reasonable and appropriate. For the purposes of this report, the hydrologic conclusions drawn in SCP Section 8.4.3 and the analyses performed by Fernandez et al. regarding the hydrologic effects of an exploratory shaft are considered valid and appropriate on the basis of the reviews conducted for this report. As explained in SCP Section 8.4.3, the remaining uncertainties about these effects can be compensated for by design controls. These effects are summarized in the following paragraph.

The analyses summarized in the SCP suggest that water moving downward from site characterization activities at the ground surface would appreciably affect saturation levels in the underlying rock for no more than about 10 meters below the surface. The DOE intends to carefully control and limit the introduction of water directly to the underground rock during site characterization. This water would penetrate only limited distances because the low pressures and limited durations of application will not force the water through the rock; even in fractures, the appreciable movement is expected to be 10 meters or less, although uncertainties exist because of the largely unknown hydraulic properties of the fractures. The resulting changes to rock saturation are expected to be small and limited to the short distances that appreciable amounts of water are expected to travel from the shafts. Furthermore, the ventilation systems that will be used during the tens of years that the shafts will remain open are expected to dry the surrounding rock, decreasing the saturation levels there until the repository is closed. The time for transient pulses of water to propagate downward through the unsaturated rock probably would be long, perhaps hundreds of thousands of years. The studies of fluid movement and of vapor movement suggest that the shafts themselves will not become preferential pathways for the movement of liquid water, water vapor, or air.

Analyses of changes to geochemical conditions

Section 8.4.3.2.2 of the SCP reviews analyses of the effects on geochemical conditions that might be exerted by fluids and other materials to be introduced into the rock during the construction of the ESF and during the operations there. It also reviews an analysis of the changes that a concrete shaft liner might introduce in the geochemical conditions of the rock.

These analyses suggest that none of the materials to be introduced will affect existing chemical conditions except in the small volumes of rock near the points of introduction. The distance of penetration by hydrocarbons and solvents, even when postulated interactions lower their viscosities, is expected to be no more than a few centimeters. Biological activity accompanying such penetration is expected to be limited to the distances of penetration, and no detrimental biological effects were identified in the analysis. Changes in the ionic composition of water near the concrete liner have been identified in laboratory studies. These changes and the formation of precipitates that result from them are localized phenomena that are expected to occur only near the shaft itself.

Analyses of-alterations in thermal and mechanical properties

In preparation for designing the ESF, the DOE carried out thermal and mechanical analyses. Section 8.4.3.2.3 of the SCP summarizes selected analyses chosen from the work that has been reported.

Many of the available results deal with the stability of the underground openings. The analyses most applicable to studies of the long-term effects of the ESF deal with potential alterations to the rock around the shaft, around the excavations that will be part of the ESF, and near the ESF pad at the surface. They also deal with the effects of removing the concrete liner from the shaft. One set of analyses estimates the changes in rock-mass permeability due to the excavation of the shaft: the estimated changes decrease rapidly with increasing distance from the shaft, becoming less than a factor of 2 at distances beyond 8 meters. These analyses are believed to be conservative in that they overestimate the changes in permeability; they also include the effects of removing the liner. Other analyses suggest that effects due to the construction of drifts in the ESF will be similarly localized; some of these analyses include thermal effects from waste in the repository of which the ESF would eventually become a part. Analyses of the blasting to be conducted in preparing the ESF pad show that controlled blasting can limit damage to less than a few meters from the pad and major cracking to less than 1 meter. All of these analyses suggest that the thermal and mechanical effects of the ESF will be confined to the rock close to the excavations.

Design features that may contribute to performance

Section 8.4.3.2.4 of the SCP supplements the preceding summaries of analyses by listing 12 design features and considerations that will contribute to the performance of the site or will help to mitigate potentially deleterious effects. Some of these features are especially important to an examination of the effects of the ESF. For example, the section points out that the ESF will not contain emplaced waste; the waste will be a minimum of 30 meters from the ESF. Moreover, blasting activities and the introduction of water will be limited; boreholes that penetrate the repository will be in pillars that isolate them from the rest of the underground workings; these boreholes and the exploratory shafts will be sealed to prevent their becoming preferential pathways for the movement of water or vapor.

3.1.2 Summary of potential impacts on the site

Drawing on the analyses summarized in the four sections that precede it, Section 8.4.3.2.5 of the SCP describes the effects that the ESF may be expected to exert on the site. The description deals primarily with effects on the unsaturated zone. The effects that would be of most importance to waste isolation are those that might contribute to altered amounts or distributions of percolation flux, changes in hydrologic properties, and the creation of preferential pathways. Other changes discussed in the section are alterations of geochemical conditions and the effects of thermal and mechanical disturbances.

The discussion treats separately each of the five categories of activities that might affect the site: surface related activities, drilling activities, exploratory shaft construction, underground construction of drifts and testing alcoves, and ESF testing activities. For each of these categories, the discussion reviews separately the possibilities for inducing the hydrologic, geochemical, and thermal and mechanical effects listed in the preceding paragraph.

The discussion points out that some of the effects of constructing and operating an ESF would be transient. For example, the introduction of limited amounts of water to the rock around a shaft could bring about localized changes in saturation, but they would be short-lived on a time scale like the 10,000-year period of waste isolation. Other effects would be essentially permanent, for example, the backfilled shafts would be present at the site indefinitely.

None of these effects, transient or permanent, is judged in Section 8.4.3.2.5 to cause any but localized effects on the site. Minor changes in flux could be expected, but only in small zones near the places where water is introduced; moreover, they would generally be transient. None of the changes to hydrologic, geochemical, or thermal and mechanical properties listed above appears to extend over more than small volumes of rock. The volumes in which the limited changes might occur are separated from the repository areas in which waste may eventually be emplaced. None of the penetrations into the rock is expected to become preferential pathways for the movement of fluids and vapors; furthermore, the penetrations themselves are so far removed from future waste emplacement areas that fluids and vapors moving through them would not be expected to carry radionuclides. The reasoning that leads to these conclusions is extensive, and the reader who wishes to follow it is referred to the SCP itself.

3.1.3 Summary of impacts on postclosure performance

Drawing on the discussion of the effects that site characterization might have on the site, Section 8.4.3.3.1 of the SCP examines the possibility that these effects could adversely affect the waste isolation capability of the site. This examination, though directed at all the effects of site characterization, pays particular attention to the effects of the ESF and is therefore appropriate for summary in this report. In summarizing Section 8.4.3.3.1, this report reviews primarily the potential effects on waste isolation (i.e., on achieving compliance with the performance objective governing releases from the total system). Because of the comprehensive scope of the total system objective, this report does not summarize the SCP discussion of the three subsystem performance objectives: waste package lifetime, releases from the engineered barrier system, and ground-water travel time. The reader who is interested in them is referred to Sections 8.4.3.3.2 through 8.4.3.3.4 of the SCP. Those sections conclude that site characterization activities, including the construction and operation of the ESF, will not adversely affect the ability of the site to meet the three subsystem objectives.

Section 8.4.3.3.1 examines in three separate discussions the effects of an ESF. The first discussion seeks to determine whether the effects would adversely affect waste isolation if conditions at the site remain as they are now during the 10,000-year waste isolation period. Because the regulations governing waste isolation require that compliance be demonstrated under possible changed conditions in the future, the second and third parts deal with such conditions. The second discussion seeks to determine whether the effects of the ESF would contribute to a loss of waste isolation under conditions that, though not now present at the site, are likely to occur during the next 10,000 years. The third discussion seeks to make the same determination under unlikely future conditions that would disrupt the site. Both of the two latter discussions examine each of the classes of scenarios (i.e., hypothetical sequences of future events and processes) that have been generated for guiding site characterization. Section 8.3.5.13 of the SCP reviews the generation of the scenario classes and explains how they are used in demonstrating compliance with performance objectives. Although these scenario classes are not necessarily the final classes that will be examined in the safety analysis report, they cover the potential disruptions that are currently thought to be worthy of study during site characterization.

The examination of waste isolation pays particular attention to the scenario class that includes surface flooding. An analysis directed toward this hypothetical sequence of events assumes that the probable maximum flood occurs in the floor of the wash in which the exploratory shafts are located. The probable maximum flood would not fill the wash to a level that would allow water to flow directly into the shaft, even when the level is raised by debris in the flood waters. The analysis therefore assumes that water from the flood enters the backfilled, unlined exploratory shaft through fractures in the rock below the flood water. To be conservative, the analysis also assumes that the shaft itself is not sealed, although the shaft design calls for seals that would impede the movement of water through the shaft. Under these conservative assumptions, the amount of water that might enter through fractures assumed to intersect the shaft is shown in the analysis to be well within the drainage capability of the ESF. It appears, in fact, to be well within the the drainage capability of the sump at the bottom of the shaft (i.e., the portion of the shaft below the horizontal workings that are the main test level in the ESF). The water would flow out the bottom of the shaft and, because of the distance between the shaft and the emplaced waste, would not contribute to a breach of waste isolation.

The three discussions conclude that the presence of the effects induced by site characterization probably will not significantly affect the ability of the site to meet the regulations governing waste isolation. In particular, the effects of the ESF, reviewed in Section 3.1.2 above, are not expected to impair waste isolation, either under the existing conditions or under the changed conditions that may occur in the future. This conclusion follows closely from the findings that the ESF is not likely to change hydrologic conditions--either flux or hydrologic properties--significantly; that changes in geochemical, thermal, and mechanical conditions probably are local and insignificant; and that the ESF is not expected to create preferential pathways for the transport of radionuclides.

3.1.4 Effects of shaft construction at alternative shaft locations; TAR Part II - Element 2

In general, the results reached in SCP Section 8.4.3.3.1 and summarized above are equally applicable to each of the five alternative locations in the Bertram report. The analyses of water infiltration from the surface are based on properties of the rock near the surface; although these properties are not precisely the same at each location, the conclusion that surficial water penetrates only short distances is not sensitive to these details. The analyses of the movement of water introduced during the construction of the shafts use the properties of the rock through which the shafts are sunk. This rock is essentially the same at each location; although the thicknesses of the rock formations vary somewhat among the locations, the results of the analyses, that the water would not penetrate far into the rock, are not sensitive to these thicknesses. The predicted transit times for downward-moving pulses of water would vary somewhat among the locations, because the times depend on the thicknesses of the rock formations; in fact, the original calculations used a stratigraphy that does not occur specifically at any of the locations. The principal conclusion drawn from the transit-time analyses, that the times are long, is not sensitive to variations in thickness within the range that occurs among the locations.

Similarly, conclusions drawn from the geochemical, thermal, and mechanical analyses do not depend sensitively on the differences that exist among the rock formations at the five locations. These analyses depend primarily on local properties of the rock. The same types of rock appear at all five locations, and the available data do not suggest that these properties vary significantly among the locations.

Because the analyses apply to all five locations, the conclusions about the effects of construction, operations, and testing in the ESF, summarized in Section 3.1.2 above, also apply to all of them. Changes in flux due to these activities probably will occur only in limited regions and generally are expected to be transient; changes in hydrologic, chemical, or mechanical properties probably will extend only over small volumes of rock; and the penetrations into the rock are not expected to become preferential pathways for fluid or vapor movement. Furthermore, at all the locations, no waste would be emplaced near the shafts.

Section 3.1.3 above reaches another conclusion that applies to all five locations: that the long-term effects of the shafts probably will not affect the waste-isolation capability of the site. This conclusion applies to all the locations because the analyses that lead to it are essentially independent of the specific properties of each of the locations. Among the estimates of the effects on waste isolation, the analysis of the flooding event probably is the one that is the most dependent on characteristics of the individual locations. That analysis, summarized in Section 8.4.3.3.1.2 of the SCP, is directed toward the currently proposed location (location 4 in the Bertram report). It shows that flooding in the wash where the shafts will have been sunk is not expected to contribute to a breach of waste isolation.

The numerical details of the flood analysis could be expected to be somewhat different for locations 3 and 5, which the Bertram report shows as also partially in a wash. The qualitative result would, however, be similar, because shafts sunk at locations 3 and 5 would, like the shafts at location 4, be sunk from points high enough above the level of the probable maximum flood to make the probability of significant water infiltration negligible. Sinking the shafts at location 1 or 2, neither of which is in a wash, would obviate the need for any analysis of flooding there. Locations 1 and 2, in particular, are at the crest of Yucca Mountain and could not be affected by a channeled flood. The available analyses suggest that little would be gained by using one of the other locations, because no significant effects on waste isolation are to be expected from flooding even at the current location. The most that would be gained would be extra confidence that flooding will not detract from waste isolation and confidence against the possibility that the current analyses might prove to be unsupported by evidence collected in the future. Those analyses are so conservative, however, that future site characterization is unlikely to provide data that lie outside the range chosen for the analyses.

The flood analysis uses the hydrologic properties of the rock in which the ESF would be built. In particular, the analysis uses the bulk hydraulic conductivity of the Topopah Spring welded unit to show that the ESF is capable of draining the flood water assumed to enter the shaft. The analysis also shows that the sump at the bottom of an exploratory shaft is capable of draining all this water; no drainage from the rest of the ESF would be required. At all the locations except location 2, the bottom of the shaft would be in the unit labeled TSw2 in Figure 2-17; at location 2 the bottom would be in TSw3. The water-transmitting properties of these subunits are similar, and the conclusion would be the same for all five locations: that the ESF, and probably the sump alone, can transmit the water conservatively assumed to enter the shaft from the probable maximum flood.

The results of the available analyses, therefore, apply to all five shaft locations. Shafts at any of these locations are not expected to affect significantly the waste isolation capability of a repository associated with the shafts.

3.2 Influence of These Results on the Selection of the Shaft Location

When the DOE made the final selection of a location for the exploratory shafts (Bertram, 1984), none of the selection criteria explicitly addressed the long-term effects of a shaft on waste isolation. Since that time, several analyses have studied such effects. Section 3.1 of this report summarizes those analyses, which are described in more detail in the Yucca Mountain SCP. It also summarizes the reasoning by which the DOE concluded from those analyses that a shaft at none of the five alternative locations would detract from the long-term waste isolation that a repository at Yucca Mountain would have to provide.

This conclusion implies that a selection criterion explicitly addressing the long-term effects of exploratory shafts would not have discriminated effectively among the five locations examined in the selection process. The reasoning that led to the selection of the current location would, therefore, not have been changed by the inclusion of such a criterion.

4 Review of Conclusions

This chapter summarizes the conclusions that this report reaches regarding the evaluation of alternative shaft locations. Section 4.1 outlines the regulatory implications (with respect to the NRC postclosure performance objectives in 10 CFR Part 60) of selecting an ESF site, thereby providing an overall perspective for reaching a selection decision. Section 4.2 links these conclusions to the site characterization plan by explaining how the testing emphasis that resulted from the performance-allocation process is consistent with the site selected for an ESF. Section 4.3 then presents the specific conclusions reached as part of this evaluation.

4.1 Regulatory implications for siting an exploratory-shaft facility

As part of the Technical Assessment Review of the ESF Title I design, a comparative evaluation of alternative ESF locations (discussed in Chapters 2 and 3) has been completed. The comparative evaluation of ESF locations is intended to identify any significant differences between alternative locations in their ability to isolate waste, with and without an ESF, and what influence, if any, these differences might have had on the selection of the preferred shaft location if waste isolation had been a consideration in the location selection process.

The conclusions reached in this comparative evaluation should be considered in the perspective of the regulatory requirements. The primary regulatory requirements associated with the comparative evaluation are the broad postclosure performance objectives of 10 CFR Part 60 Subpart E (60.112 and 60.113), and the site characterization requirements of 10 CFR Part 60, Subpart B (60.15(d)(1) and 60.17(a)(2)(iii)). These broad requirements are the subject of discussion in Chapters 2 and 3 of this report. Criteria for selecting and locating an ESF, based on differences among locations in their waste isolation capability, depend on such considerations as relative differences among alternative locations, overall estimates of each location with respect to the regulatory requirements, and uncertainties in both the relative differences and overall estimates. Figure 13 displays these considerations; judgments of whether any relative differences in location are significant with respect to waste isolation is dependent on the collective evaluation of all the generalized decision factors shown in Figure 13.

The importance of the generalized decision factors is illustrated in Figure 14 by two examples. The figure uses a probability distribution function for a generalized performance measure as an estimate of the ability of two hypothetical locations to isolate waste. It also shows a hypothetical regulatory requirement stated in terms of a value for the performance measure. In one example (Case A), only small differences exist in the estimates of the relative abilities of the alternative locations to isolate wastes, and the absolute estimates are near the regulatory requirements. In the other example (Case B), large differences exist in the relative estimates, but the absolute estimates are far below the regulatory requirements. In both examples, the absolute estimates meet the regulatory requirements.

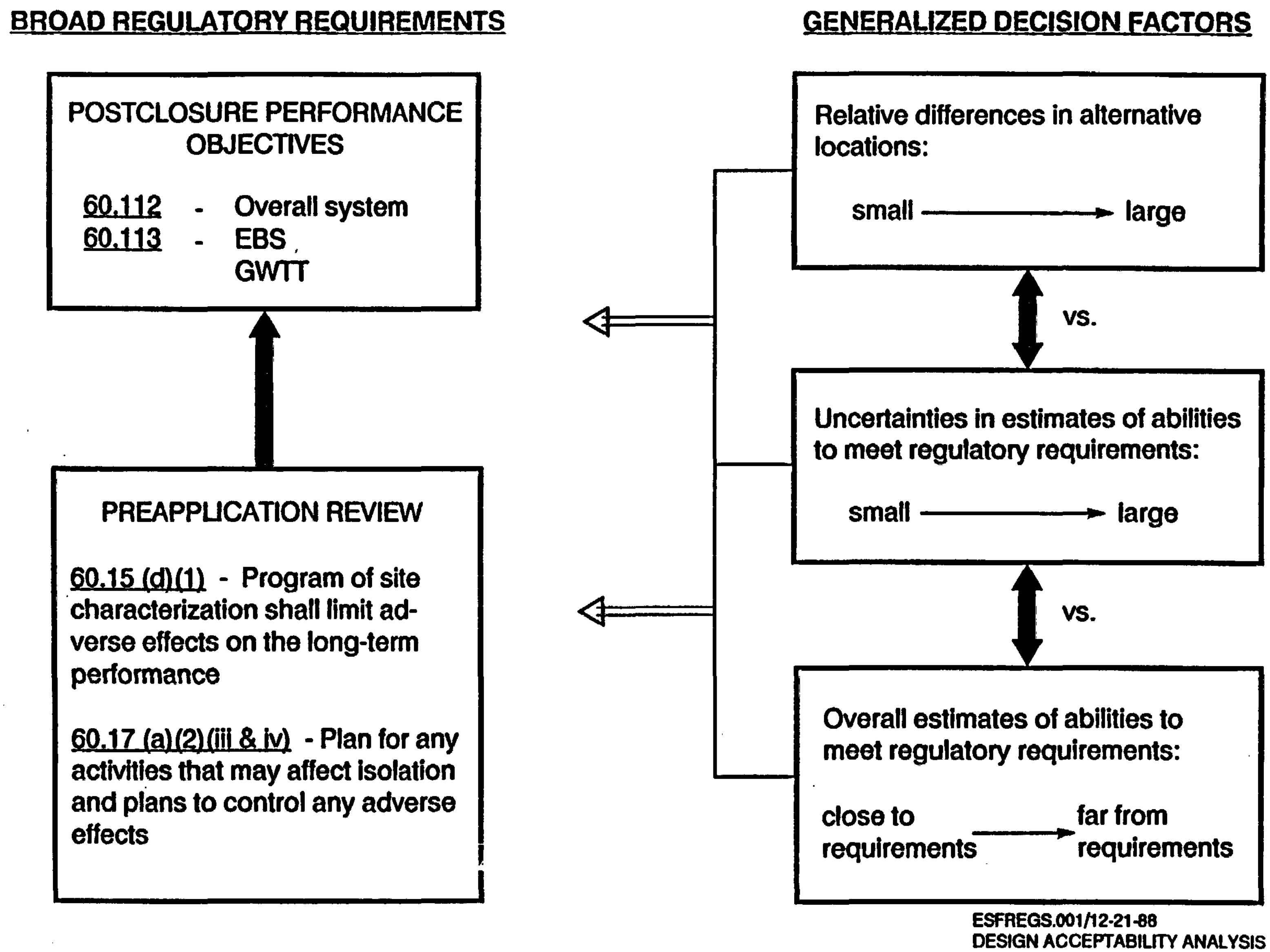
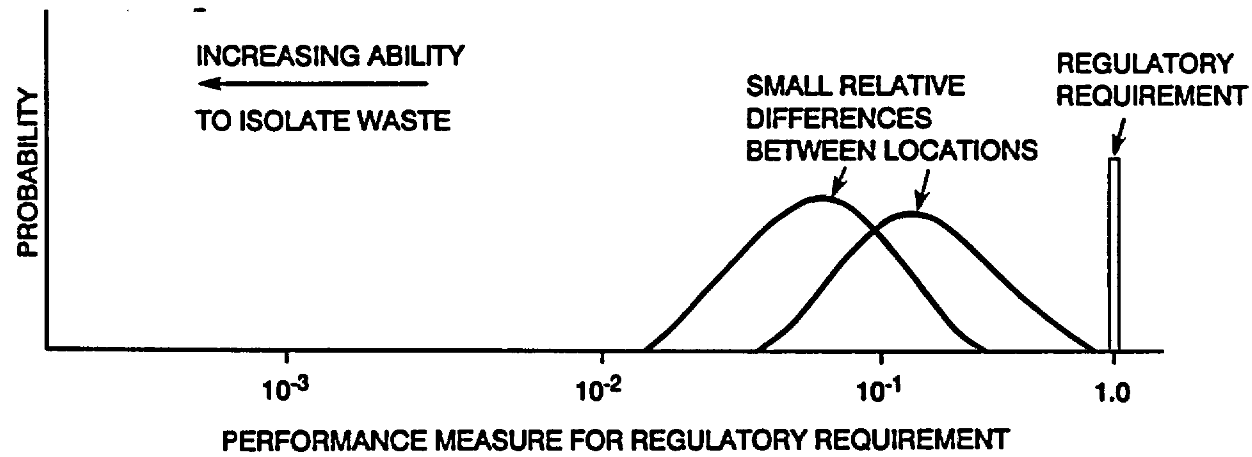


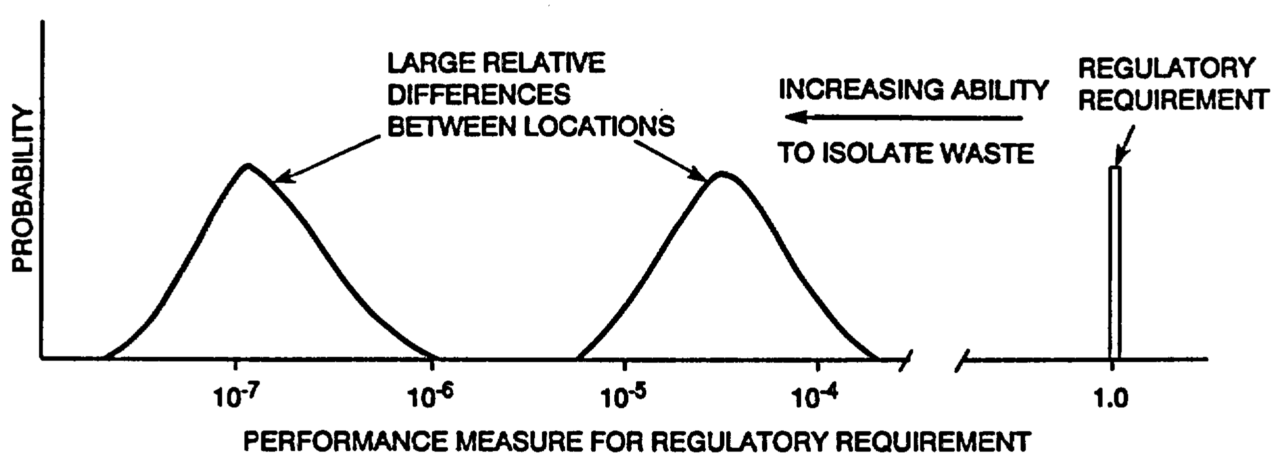
Figure 13. Factors to consider in selecting an ESF location with respect to waste isolation.

CASE A



In Case A, uncertainties in release estimates are critical, and the relative differences in alternative locations may be significant, possibly even for small uncertainties. (It is necessary to compare uncertainties to the relative estimates; i.e., the uncertainties may overwhelm the small relative differences.)

CASE B



In Case B, uncertainties in release estimates are not important unless they are extremely large, and the relative differences in alternative locations are not likely to be significant.

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Figure 14. Examples of differences in alternative shaft locations and their significance in terms of regulatory requirements.

In Case A, uncertainties in the release estimates are extremely important, and the relative differences, though small, may be significant, because both estimates are near the value set by the regulatory requirement. However, the small relative differences must be compared with the estimated uncertainties expressed by the width of the distribution curves shown in Figure 14; the overall uncertainty estimates may overwhelm any relative differences. For this example, the location that is less favorable for obtaining the site data that are most critical (on the conservative side) to quantifying the uncertainties associated with the regulatory requirements may not be a suitable candidate for an ESF and, in the extreme case, for a repository (i.e., any appreciable unfavorable change brought about by site characterization in the distribution for the less favorable site could result in a violation of the requirement). Thus, Case A is an example where relatively small differences may be significant.

In Case B, uncertainties in the release estimates are not significant (in terms of location selection) unless they are extremely large, and the relative differences are not likely to be significant. For this example, both locations are likely to be suitable candidates for an ESF. Thus, Case B is an example where relatively large differences in the ability to isolate waste are likely to be not significant for selecting a location for an ESF.

These two examples demonstrate that judgments on alternative locations are dependent on more than the relative differences between sites. In fact, for Case B in Figure 14, the less favorable site may be the better location for an ESF, because this location would permit the obtaining of site data most critical (on the conservative side) to quantifying the uncertainties associated with the regulatory requirement.

4.2 Linkage to the site characterization plan

As discussed in SCP Sections 8.0 and 8.1, the performance allocation process used to develop the information needs was completed conservatively. Issue resolution strategies for the NRC regulatory requirements of 10 CFR Part 60, Subpart E (60.112 and 60.113), discussed in the SCP sections on Issues 1.1 through 1.6, reflect this principle by setting conservative performance measures. This conservatism resulted in information needs that emphasize not only the expected site performance, but also the range of potential uncertainties in site performance. Thus, the execution of performance allocation has resulted in a site program that reflects an emphasis on obtaining site data describing conditions that could be the most detrimental to site performance. The selection of an ESF location needs to be compatible with this intentional bias; it should provide a location where critical data can be gathered to confirm or deny assumptions, to choose among proposed conceptual models, and to reduce uncertainties in overall site performance, with emphasis on parameters most critical to repository site performance.

This overall philosophy is consistent with the comparative evaluation made in Chapter 2, which, besides identifying some relative differences between locations, shows that the larger uncertainties associated with critical parameters can be studied best at the currently proposed shaft location. In other words, this result of the comparative evaluation is consistent with the conservative execution of performance allocation in the SCP.

4.3 Summary of conclusions for alternative shaft locations

Chapter 2 of this report examines the waste isolation capabilities of the five alternative shaft locations that the DOE examined before selecting its proposed location. It also examines the southern part of the repository area, which was not considered by the selection process. The examination uses measured characteristics of these locations as surrogates for a detailed prediction of the relative ability of the locations to isolate waste. A comparison of these characteristics suggests that the locations do not differ significantly in their ability to meet regulatory requirements. Two relative differences appear to exist among the locations: (1) the ground-water flow times through the unsaturated rock formations below the current location are probably somewhat shorter than the corresponding times at the other locations; (2) if lateral diversion or infiltration through washes causes the ground-water percolation flux at depth to be different at different parts of the repository site, this flux may be larger at the current location than at the others. The second difference would exist only under conditions that are currently unproved: significant lateral movement of water at or near rock unit contacts above the proposed repository horizon, or greater localized percolation beneath washes than beneath other parts of Yucca Mountain. Neither of these two differences is likely to have a significant effect on the ability of the location to isolate waste. Even the shorter ground-water travel times appear to be long enough to contribute to compliance with the standards for waste isolation. In terms of the generic examples discussed above, the comparison of the locations is currently thought to be similar to Case B, except that the relative differences among the actual locations are not necessarily "large". The characteristics of the locations are distinguishable on the basis of currently available data, but the differences do not appear to be significant to waste isolation.

If waste isolation capability had been an explicit criterion for the selection of a shaft location, the criterion would probably have had little, if any, effect on the final choice. The effect that it would have had depends on how it had been stated. If it had been stated so as to favor the selection of locations that are likely to meet the waste isolation regulations, it would not have discriminated effectively among the five locations; the surrogate characteristics are favorable at all the locations. Such a nondiscriminating statement would have left the selection to the criteria used in the Bertram report (1984), and the current location would have been selected.

A more useful statement of the criterion would have been a statement that explicitly favored the selection of locations where data could be obtained to address the uncertainties associated with the less favorable site characteristics. As explained in Chapter 1, some of the criteria actually used in the selection implicitly favored such locations. In principle, an explicit statement of this kind would be useful because such locations are the most worthy of detailed study: studies there would help to establish lower bounds on the waste isolation capability of the rest of the site, increasing that the rest of the site, where waste would actually be emplaced, would meet the regulatory requirements. This second possible statement of the criterion would have tended to favor the current site. Added to the other criteria used in the Bertram report, it, like the first statement, would have led to a selection of the current site.

Chapter 3 of this report reviews the analyses that examine the effects of a shaft on the waste isolation capability of a repository associated with the shaft. These analyses suggest that a shaft is expected to have no significant effects on waste isolation, regardless of its location within the site proposed for development at Yucca Mountain. A selection criterion based on such effects would not have discriminated among the five alternative shaft locations. Therefore, if such a criterion had been among those used in selecting the final location, it would not have affected the choice of the currently proposed location.

The examination described in this report leads to a conclusion that selection criteria explicitly based on waste isolation capability would not have changed the location currently proposed for the exploratory shafts at Yucca Mountain.

The overall conclusions and recommendations based on the comparative evalaution are the following:

1. Differences among the alternative shaft locations for currently expected conditions are not significant to waste isolation. This is because all the locations are expected to have conditions that would allow regulatory requirements to be met by wide margins.

2. Differences among the alternative shaft locations might be significant if future data show that widespread large-flux conditions exist at the repository site (currently considered unlikely) or could result from future disruptions of current conditions. Significant differences might also exist if current or future local concentrations of large flux are caused by subsurface lateral diversion or spatially variable pulses of surface infiltration. In either of these cases, locations toward the northeast would be more likely to have groundwater flow times to the water table less than the period of regulatory concern (10,000 yr) in the local zones of flux concentration. Under these conditions evaluations of other natural barriers including geochemical retardation, flow times in the saturated zone, and longer flow times outside the zones of flux concentrations may be necessary to demonstrate adequate waste isolation capabilities for the overall site.

3. The presence of a shaft at any of the locations is not expected to affect significantly the waste isolation capability of a repository.

4. The current shaft location is the preferred location for characterization. Although the relative differences discussed in conclusions 1 and 2 are judged not significant to the waste isolation capabilities of the overall site, they suggest that the characteristics of the current location may be less favorable than the characteristics of the other locations. Therefore, the current location is the most suitable for a conservative approach to collecting data to reduce

uncertainties associated with the models, assumptions, and processes that affect predictions of waste isolation.

5. The addition of a waste isolation criterion to the set of criteria used in selecting a shaft location would not have changed the selection of the current location, but might have strengthened the scientific basis for choosing it, on the basis of conclusion 4.

6. The DOE should continue to support the current ESF location as the preferred location for the site-characterization program, on the basis of conclusions 1 through 5.

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APPENDIX K-1

Administrative Summary

Appendix K.1

Background References:

The following background materials are quoted to establish the record of concerns expressed by various parties that pertain specifically to the task undertaken by subcommittee 3 to compare the isolation potential of alternative ESF locations.

Viewgraphs - October 19 - 21, 1988; Dinesh Gupta; NRC/DOE Meeting

"Concerns on Locations of ES-1 & ES-2

Same design criteria must apply to ESF and Repository

DOE should demonstrate that the decision process that led to the selection of exploratory shaft locations close to a wash adequately considered 10 CFR 60 requirements

DOE should demonstrate that ESF design limits adverse impacts on long-term repository performance

The shaft locations decision process should demonstrate that 'particular attention (was given) to the alternatives that would provide longer radionuclide containment and isolation' (10 CFR 60.21(c)(1)(ii)(d))

As implementation of design control process the DOE should identify specific entity that was responsible for ensuring that 10 CFR 60 requirements are incorporated in the shaft location selection process

The decision process for shaft location selection should demonstrate that qualified data were used in arriving at the decision

DOE should provide documentation of the design control process for establishing tie between SDRD requirements and 10 CFR 60 requirements governing shaft locations. Examples

* shaft locations
* implementation of 10 CFR 60 requirements in the shaft location selection process including use of qualified data
* verification of adequacy of shaft locations and ESF/repository design interfaces"

Letter - November 14, 1988; Linehan, NRC, to Stein, DOE;

Enclosure: "DOE presented its approach to evaluating alternative exploratory shaft locations. A copy of this is contained in Attachment 3. The NRC staff noted that it believes that the DOE approach by itself would not be acceptable; however further staff discussion would be necessary before a final position would be taken."

Attachment 3: DOE approach to evaluating alternative shaft locations: "Perform comparative evaluations related to alternative shaft locations to examine:

" - any significant differences in the capability of these locations to isolate or contain wastes"
and
" - any significant adverse effects that a shaft might have on the ability of the location to contain and isolate waste"

Letter - December 12, 1988, Blanchard, DOE, to Gertz, DOE

Enclosure - page 4: "the TAR team will perform a comparative evaluation of alternative ESF locations. The comparative evaluation is intended to identify any significant differences, for alternative locations which were specifically considered earlier, in their potential to isolate or contain wastes, with and without the ESF present, and what influence, if any, these differences might have had on the selection of the preferred shaft location had they been an explicit consideration in the location-selection process (see Appendix I, NRC letter, Attachment 3). The evaluation will also compare the waste isolation potential of alternative ESF locations to the waste- isolation of the overall site. The evaluation will consider current site conditions, expected changes in current conditions over the next 10,000 years, low-probability disruptive events and processes over the next 10,000 years, and alternative conceptual models of conditions at the site."

TAR ACTIVITIES of SUBCOMMITTEE 3

Initial Committee Meeting: December 12, 1988

- Formation of Subcommittee 3
- Appointment of subcommittee members
  Scott Sinnock, SNL, Chairman
  Bill Wilson, USGS
  Felton Bingham, SNL
  Jeff Kimball, DOE/HQ
  Scott Van Camp, Weston
- See TAR Committee records for training and other record pertaining to TAR Committee as a whole

Initial Subcommittee Meeting: December 13, 1988

- Preparation of Schedule for Subcommittee 3 and assignment of tasks to subcommittee members (see attachment 1)

- Preparation of initial outlines for (1) Review Record Memorandum Chapter 5 (note: RRM outline has changed since initial subcommittee meeting, current RRM chapter 3 was then designated chapter 5) and (2) a backup report on comparison of alternative shaft locations (see attachment 1)

Preparation of Shaft Comparison Report: Appendix J of this RRM

Lead responsibility for preparing each section of the comparative evaluation report (Appendix J of this RRM) was assigned individual subcommittee members (see Attachment 1). Subsequent to these initial assignments, Jeff Kimball took lead responsibility for preparing the working drafts of Sections 1 and 4. These individuals produced initial working drafts of their appropriate sections on word processing systems convenient for their use.

Scott Sinnock and Felton Bingham produced working notes and draft text for Sections 2.1 and 2.2 (Sinnock) and 3 (Bingham). This material was based on discussions among Max Blanchard, Mike Voegle, Gordon Apell, Jerry King, Jean Younker, Bob Levich, Sinnock, and Bingham. These discussions were held in anticipation of a need to formally document the comparison of alternative shaft locations in term of post closure performance to augment the comparisons done by Bertram (1984). During these discussions the general strategy for addressing the comparative evaluations for shaft locations was developed. Sinnock proposed the strategy for using discriminating, mappable site characteristics as surrogates for comparing the isolation potential of alternative shaft locations in the context of the variability of these surrogates throughout the site. Tentative lists of these surrogates were developed by group discussions and Sinnock was assigned the task of developing text to use such surrogates to make the comparisons. Bingham proposed that the information in Section 8.4.3 of the SCP be used as a basis for developing Section 3 of the comparative evaluation report (effects of the shaft on performance at alternative locations), and he was assigned the task of developing working text to assess these effects.

Copies of these working materials were distributed to subcommittee members. Initial tasks were assigned to review the technical bases of these working materials (see attachment 1). Scott Van Camp compared the initial list of surrogates identified by Sinnock to the performance allocation tables and alternative conceptual model tables for hydrology in the SCP to determine if any modifications to the surrogate to be used should be made to more completely or appropriately address the performance of alternative locations. Several suggestions were made and discussed, and the original list of surrogates was agreed upon. Bill Wilson reviewed the relation of the surrogates to potential performance differences among the alternative sites and suggested strengthening the arguments that were made in the working text to establish these relationships. Bill Wilson also took responsibility to review the technical, hydrologic bases for Section 8.4.3 of the SCP to assure subcommittee members that conclusions drawn in Section 3, which rely on the hydrologic information in SCP section 8.4.3, were consistent with current hydrologic data and understanding. To conduct this review, Wilson solicited and received the support of several scientists who reviewed specific references cited in SCP 8.4.3 (see Appendix K.2)

Based on these initial reviews the responsible leads for Sections 1 - 4 prepared working drafts of the text. These drafts were circulated to all subcommittee members by the individual leads as changes were made. Continual updates and revisions were made based on verbal comments and text markups from other subcommittee members. This process was conducted in Las Vegas where all subcommittee members were located during the weeks of December 19, 1988 and January 3, 1989. Sinnock submitted a work request to the Interactive Graphics Information System at Sandia national Laboratories, Division 6315, to initiate work to produce maps of the surrogate site characteristics at the Yucca Mountain site (see Appendix K.2). During the week of January 3, a surveillance of work to date was conducted by QA. The surveillance team was provided with working draft materials. An early version of the Appendix J report was submitted to the TAR Committee chairman, Jerry King, on January 6, 1989 for wider distribution to all TAR Committee members and transmittal to DOE management personnel in Washington, DC, and Las Vegas, Nevada for their information.

During the week of January 9, Felton Bingham Bill Wilson were the only subcommittee members working in Las Vegas. Scott Sinnock was absent due to family commitments and Jeff Kimball and Scott Van Camp were in their home offices in Washington, DC. Bingham and Wilson continued to revise the report based on comments from subcommittee members and from personnel supplying groundwater travel time calculations to the subcommittee for possible inclusion in the report. During this period, Bingham took on a major role in coordinating the editing and word processing logistics for the report. At this time he moved all word processing files for the various section to a central file on the SAIC VAX-based word processor. All subsequent revisions were wordprocessed by SAIC secretarial personnel based on markup of text hardcopy. In the period between the submittal of a working draft to King on January 6, 1989 and transmittal of an information package to DOE management personnel on January 13, 1989, a major decision was made by Bingham and Wilson and concurred in by Sinnock (who came to the office on the afternoon of January 12 for a briefing). The decision was to remove the text from the Appendix J and the associated text from the working draft of Chapter 3 of the RRM (see next section of this Appendix K.1) that had been written by Sinnock in anticipation of receiving the groundwater travel time calculations from personnel at Sandia National Laboratories responsible for WBS element 1.2.1.4.1 (Flow and Radionuclide Transport). Wilson and Bingham then removed the section on groundwater travel time (Section 2.3.1 of the working draft submitted to King on January 6). The decision at that time was to retain the option to add the calculations and associated text in Section 2.3.1, if concerns about their use in Appendix J could be resolved in time to allow their inclusion.

The concerns were that the time allowed for performing and reviewing a set of calculations was insufficient for assuring the calculations reflected a realistic representation of the flow behavior at the five alternative locations. DOE management personnel were briefed in Washington, DC about the contents of the evolving RRM contents on January 17, 1989. Sinnock and Kimball attended the briefing as representatives of subcommittee 3. Management personnel expressed a consensus that a quick decision be made by the TAR team about whether to include the groundwater travel time calculations in the final RRM.

To resolve these concerns, a meeting was held in Las Vegas on January 20, 1989. Attenders were Sinnock, Wilson, Paul Kaplan (task leader for WBS 1.2.1.4.1 and the person responsible for the calculations), Ralph Peters (a Sandia staff member and member of the review team assigned to assess the calculations under Sandia's QA procedure for control of calculations, SNL Department Operating Procedure 2-4), Dwight Hoxie (USGS scientist), Jean Younker (SAIC earth scientist and manager), and Les Shepard (Sandia earth scientist and supervisor, Division 6315 at SNL).

The consensus of the meeting attenders, with a minority opinion by Sinnock, was that it was premature to include the probabilistic calculations for any of the sites or flux boundary conditions because of concerns about the defensibility of the statistical treatment of input parameters based on the sparse data available for many of the parameters, including likely but not defined correlations among the parameters. Another consensus reached, with a possible minority opinion by Kaplan, was that it would probably be defensible to use the one-dimensional deterministic calculations for flux boundary condition values up to 0.5 mm/yr. However, Sinnock and Wilson, as the subcommittee members, vetoed the use of single travel time values for the sites for several flux boundary conditions because such single values would not adequately reflect uncertainty associated with the travel time for a given flux. Therefore, the final outcome of the meeting was a decision agreeable to all attenders that no travel time calculations would be included in the Appendix J report.

On January 20, Sinnock received copies of the maps of the surrogate site characteristics from Chris Rautman, task leader for the Interactive Graphics Information System, WBS 1.2.1.3.1 (see Appendix K.2). These computer generated maps were submitted to SAIC drafting personnel for modification to publishable form as Figures 1 through 12 of the report.

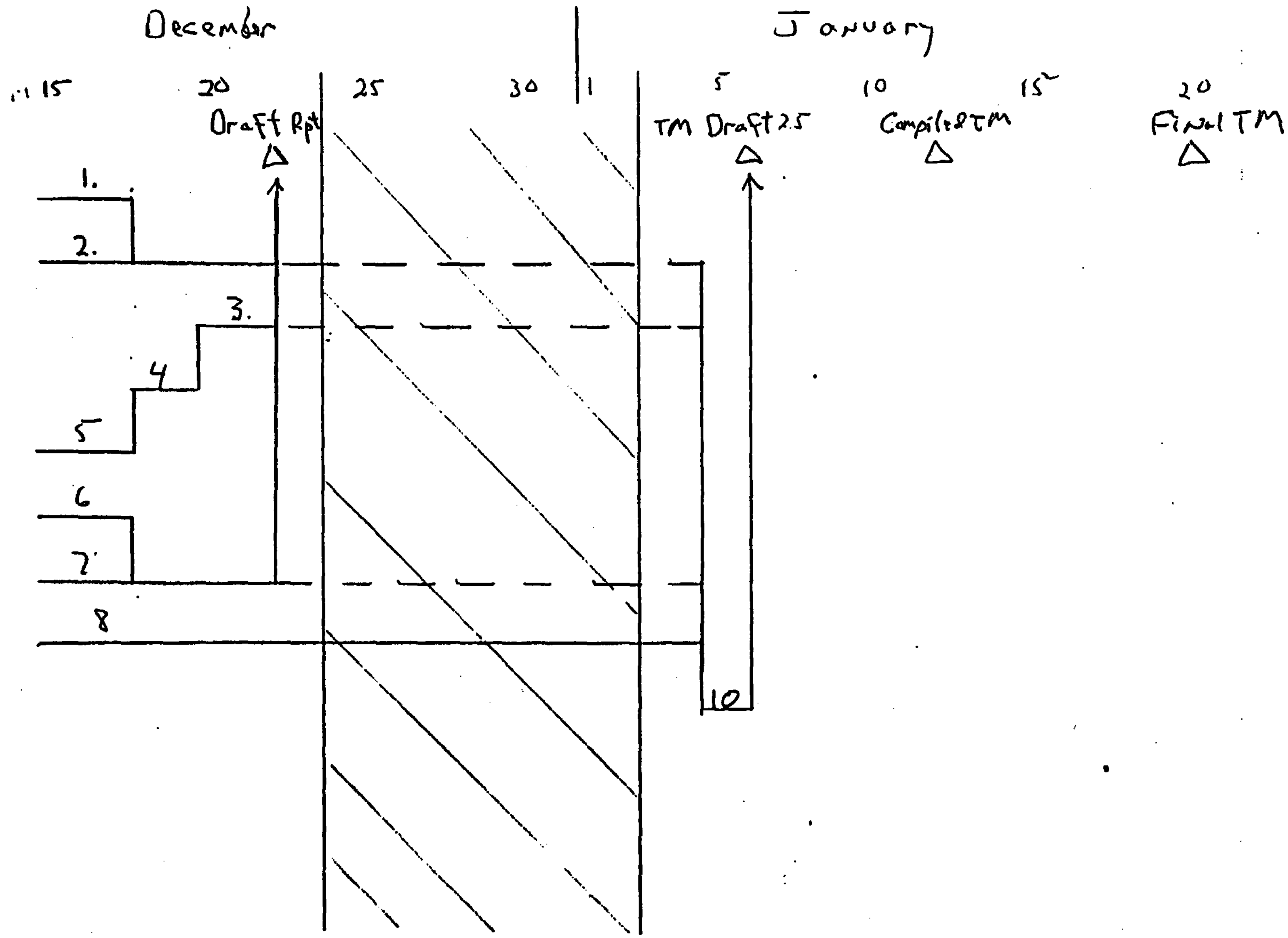
No activity of the subcommittee occurred on the first two days of the next week, January 23 and 24, 1989, because two subcommittee members were involved in a briefing to the Advisory Committee on Nuclear Waste of the NRC in Washington, DC. Beginning January 25, 1989, Sinnock undertook final editing of the report and transmitted copies to the other committee members at their home offices. The final draft was reviewed by technical editors at SAIC who established the final format and coordinated the final word processing and graphics. Based on these final editorial changes, all committee members signed a concurrence sheet attached to the front of the report on February 1, 1989. The concurrence sheet was circulated to subcommittee members along with the final draft of the report by overnight mail during the week of February 1. This final draft, concurred in by all subcommittee members constitutes the first formal version of the report in Appendix J.

Preparation of Chapter 3 of this RRM

Lead responsibility for preparing each section of Chapter 3 of the Review Record Memorandum summarizing the comparative evaluation report in Appendix J of this RRM was assigned individual subcommittee members (see Attachment 1, noting that at the time of initial assignments the subcommittee assumed the memo, TARM, would place the comparative evaluation summary in a section 2.5). Subsequent to these initial assignments, Jeff Kimball took lead responsibility for preparing the working drafts of Sections 2.5.1 (currently RRM Chapter 3.1) and Section 2.5.3 (currently RRM Chapter 3.3). Thus, Kimball and Felton Bingham produced initial working drafts of their appropriate sections on word processing systems convenient for their use. Bill Wilson and Scott Van Camp provided comments to Bingham who coordinated the revisions for Chapter 3. Scott Sinnock was exclusively occupied with preparation of sections of Appendix J and did not review early working drafts of Chapter 3. By January 6, 1989, an initial working draft had been compiled based on the reviews of the four subcommittee members working on Chapter 3. During this time Bingham also transferred all word-processing files to the SAIC VAX-based word processor, and subsequent revisions were word processed by SAIC secretarial support based on markups of working texts. Bingham coordinated the subcommittee's interface with the word processing personnel.

The working draft available on January 6 was transmitted to Jerry King, TAR Committee chairman for wider distribution to TAR Committee members and transmittal to DOE management personnel for information. As discussed in the previous section, Bingham, Wilson, and Sinnock decided on January 12 to remove any reference to groundwater travel time calculations from the material sent to DOE management personnel. Wilson and Bingham then removed all reference to the calculations from the working drafts sent to DOE management on January 13 by Jerry King. On January 16, Wilson and Bingham collaborated to produce a synopsis for inclusion in Chapter 3 of the relation between the surrogate site characteristics and the possible groundwater flow modes at the site to provide the perspective intended by the groundwater travel time calculations.

On January 25, 1989, Sinnock assumed a role as editor of the version of Chapter 3 that included the synopsis prepared by Wilson and Bingham. The final draft was reviewed by technical editors at SAIC who established the final format and coordinated the final word processing and graphics. Sinnock circulated the edited draft of the text along with the concurrence sheet for Chapter 3 to subcommittee members at their home offices during the week of February 1. This final draft, concurred in by all subcommittee members constitutes the first formal version of Chapter 3 of the RRM.



TAR Subcommittee on Alternative Locations
Logic Chart

K.1-8

Appendix K.1
Attachment 1
Page 1 of 3

Appendix K.1
Attachment 1
page 2 of 3

TAR SUBCOMMITTEE ON ALTERNATIVE LOCATIONS

Activities/Task Assignments

Activity	Responsible Person
1. Review Relation of Surrogates to Performance Allocation for Issues 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.10 & 1.11	SVC
2. Evaluate other potential ES sites within drift boundary relative to 5 sites (2.5.3)	SS
Evaluate spatial variations in isolation potential at five sites without ESF present (2.5.1)	
3. Rank areas, 5 sites (?)	SS/BW
4. Net effects of combined surrogates on defining isolation potential	SS/BW
5. Decide on surrogates	SS/BW
6. Assess 8.4 conclusions about impact of ES on waste isolation	BW
7. Evaluate five sites on ability to isolate waste with ESF (2.5.2)	FB
8. Define criteria for locating ES, based on differences among sites to isolate waste	JK
9. Review and Revise	All
10. Prepare TARM draft input	All

Appendix K.1
Attachment 1
Page 3 of 3

Draft Location Report (available for subgroup review Dec. 22)

Person	Section
FB	1. Background (2.5) & 2.5.4)
SS/BW	2. Comparison of alternative locations 2.1) Establish surrogates 2.2) Compare surrogates across the site (2.5.3) 2.3) Compare surrogates at ESF locations (2.5.1)
FB/BW	3. Effects of ESF on performance (2.5.2)
All	4. Summary, Conclusion, Recommendations (2.5, 2.5.4)

TARM Input Outlines

Person	Section
JK	2.5 Background, Scope
SS/BW	2.5.1 Compare ESF locations without ESF
FB/BW	2.5.2 Compare ESF locations with ESF present
SS/BW	2.5.3 Compare to variability across site
JK	2.5.4 Regulatory implications for siting ESF
All	2.5.5 Conclusion ?"If performance had been explicitly considered, it would have supported location to NE or E, including Coyote Wash, (if 2.5.2 shows no impacts of ESF on performance"?

APPENDIX K-2

Correspondence

Appendix K.2

Included in this appendix are copies of four documents (Appendices K.2.1 - K.2.4) reporting the results of independent reviews of Section 8.4.3 of the Site Characterization Plan (DOE, 1988) and parts of Fernandez et al. (1988) and West (1988). The reviews were intended to address the following questions:

- Analysis of the effects of ESF activities on the hydrologic conditions at the site:
    1. Was the model (conceptual, numerical) that was used appropriate?
    2. Were the assumptions, boundary conditions, and data that were used reasonable and appropriate?
    3. Were data uncertainties considered and conservative approaches taken?
    4. Were the conclusions that were drawn reasonable and appropriate?

- Evaluation of impacts of modified hydrologic conditions on performance

Also included are copies of two work requests (Appendix K.2.5) submitted to the Interactive Graphics Information System at Sandia National Laboratories, Division 6315, for generation of material to produce figures 1 through 12 of Appendix J; and a copy of one document transmitting computer plots of the figure material to Scott Sinnock (Appendix K.2.6). The documents are as follows:

Appendix K.2.1	Letter from S. G. Doty and J. D. Marvil to W. E. Wilson, 12/21/88: review of sections 3.0, 6.0, 7.0, and 8.0 of Fernandez et al. (1988)
Appendix K.2.2	Letter from J. Prizio to W. E. Wilson, 1/4/89:review of section 3.0 and Appendices C and D of Fernandez et al. (1988)
Appendix K.2.3	Letter from R. Trautz to W. E. Wilson, 12/22/88: review of parts of sections 4.0 and 5.0 of Fernandez et al. (1988)
Appendix K.2.4	Letter from S. G. Doty to W. E. Wilson, 12/28/88: review of West (1988)
Appendix K.2.5	Work requests for Interactive Graphics Information System submitted by S. Sinnock, received 11/10/88 and 12/20/88
Appendix K.2.6	Letter from C. A. Rautman to S. Sinnock, 1/17/89: IGIS products

Appendix K.2.1

Letter from S. G. Doty and J. D. Marvil to W. E. Wilson, 12/21/88: review of sections 3.0, 6.0, 7.0, and 8.0 Fernandez et al. (1988)

Science Applications International Corporation
An Employee-Owned Company

WBS: 1.2.3.3.6.2
QA: "N/A"

December 21, 1988

W.E. Wilson III
Yucca Mountain Project Branch
U.S. Geological Survey
P.O. Box 25046, MS-421
Denver Federal Center
Lakewood, Co 80225

Subject: Assessment of 8.4 Conclusions About Impact of ES on Waste Isolation

Dear Bill:

Josh Marvil and I have reviewed Sections 3.0, 6.0, 7.0, and 8.0 of Fernandez et al (1988). We found that the same conclusions that are drawn in SCP Section 8.4 regarding the impact of the ESF on waste isolation were also clearly and directly presented in the Fernandez paper. In general, we also found that: (1) the conceptual and numerical models used were appropriate; (2) the assumptions were conservative; (3) the boundary conditions and data inputs were reasonable, when presented; and (4) the conclusions that were drawn were reasonable and appropriate. One concern that we had was that some of the data used in the models were not included in the report, but instead were referenced. We have not checked the references, but would need to in order to determine the data's reasonableness. In the following paragraphs, our specific comments/concerns for each of the sections are addressed.

Section 3.0 Potential for enhancing radionuclide release resulting from selected water flow scenarios

1. Fernandez et al (1988) used a model involving laminar flow between parallel plates governed by the cubic law of fracture flow (pg 52). In this model, the Green-Ampt equation was used to account for matrix imbibition, and the Van Genuchten parameters from Klavetter and Peters (1986) were used to evaluate matrix pressure. The use of the Green-Ampt equation is questionable because there are more rigorous analytical and numerical methods that could have been selected (e.g. Brooks Corey, Modified Richards, Van Genuchten, Philip). The use of the cubic law equation with laminar flow is also questionable as the cubic law probably has little validity in rough-surface fractures. Also, the Van Genuchten parameters from Klavetter and Peters (1986) are in conflict with those of other researchers (Flint, unpub; Weeks; unpub).

1626 Cole Boulevard, Suite 270, Golden, Colorado 80401 (303) 231-9094
Other SAIC Offices: Albuquerque, Boston, Colorado Springs, Dayton, Huntsville, Las Vegas, Los Angeles, McLean, Oak Ridge, Orlando, Palo Alto, San Diego, Seattle, and Tucson

2. Fernandez et al (1988) did not consider the presence of perched water in any of the ES water accumulation scenarios. Perched water must be considered before construction of the ES as it poses potentially deleterious and unpredictable problems.

Section 6.0 - Potential for changing the conductivity of the shaft liner, the modified permeability zone, the shaft fill, and the shaft sump

1. Fernandez et al. (1988) assume local equilibrium for their modeling efforts. Even though this is a conservative assumption, why not consider diffusion of ionic species and chemical kinetic rate processes (we have the technology) and model the entire system more realistically?

2. In calculating diffusion through the concrete liner using Fick's Law, an empirical diffusion coefficient (ϵ) of 0.28 (p. 119) seems low. It would be interesting to know where this value came from. Similarly, the value for Eh (-256 mV, p. 122) seems low and should not be arrived at simply "to keep minerals in solution". An expected value of Eh at pH-6.9 is 816 mV (Garrels and Christ, 1965). It is recognized that Eh is difficult to measure in natural systems out of equilibrium with air because of the problem of introducing electrodes without simultaneously introducing air. The authors' have chosen a conservative value of Eh, but should explain their choice in more detail.

3. Throughout Chapter 6.0, Fernandez et al. (1988) take conservative approaches to simulate the worst-case scenarios. For the present analysis of the concrete liner, they only estimate the nature and quantity of precipitates from the interaction of ground water with the concrete liner. An analysis of the interaction of ground water, the concrete liner, and <u>tuff</u> at ambient conditions and as a function of temperature is even more important.

Section 7.0 - Potential for impacting repository performance resulting from penetration of the Calico Hills unit by the ES

The conceptual model used in this section seemed appropriate. The authors do not reach any quantitative conclusions, but merely reason that the impact of water percolating through the shaft fill and MPZ on the sorption potential of Calico Hills is negligible. It would be more appropriate to express the distribution coefficient (Kd) on a per-unit-surface area basis for fluid migration through fractured materials instead of using mass density in the definition, as the majority of flow would be through fractures.

Section 8.0 - Possible remedial measures to modify physical features associated with the exploratory shaft facility

In this section, the liner removal and MPZ restoration methods considered were appropriate, and the conclusions reached were reasonable. Due to the fact that numerical models with the associated data inputs, boundary conditions, and assumptions were not required to evaluate the remedial measures, there was little to review in this section.

Sincerely,

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

S. G. Doty/J. D. Marvil

SGD:JDM/cp

cc: R. L. Wise, SAIC-Golden
T. G. Barbour, SAIC-Golden
Project File: 527-32-1-1
YMP LRC

Appendix K.2.2

Letter from J. Prizio to W. E. Wilson, 1/4/89: review of section 3.0 and Appendices C and D Fernandez et al. (1988)

D-3790

JAN 6 1989

WBS #: 1.2.3.1
QA: QA

Memorandum

To: Bill Wilson, U.S. Geological Survey, Denver, Colorado, MS-421

From: Joe Prizio, U.S. Bureau of Reclamation, Denver, Colorado, D-3790

Subject: Technical Assessment Review Plan, Exploratory Shaft Facility (ESF) Title-I Design Acceptability Analysis and Comparative Evaluation of Alternative ESF Locations

On December 22, 1988, I sent to you a draft copy of my comments on section 8.4.3 of the SCP and Sandia report SAND85-0598. This memorandum is to transmit those comments formally. Feel free to contact me at extension 64175 if you have any questions.

Technical Assessment Review Plan (TAR Plan) Scope

The TAR Plan, dated December 12, 1988, contains two review objectives:

1) to evaluate the ESF Title I design against three general objectives in 10 CFR Part 60, namely:

a) the long-term waste isolation capability of the site will not be compromised;

b) the ability to characterize the site will not be compromised;

c) the ESF site-characterization activities will provide representative data.

2) to compare alternative ESF locations.

The TAR Package contains the documents to be reviewed, as well as resource documents that team members may use without "review" to support their evaluations. Examples of the review documents are the Generic Requirements Document/Appendix E; the ESF-SDRD, Volumes I and II; the Reference Information Base (RIB); the ESF Design Scope and Planning Document for Title I Design; and Control Drawing Number R07048A, Sheets, 1-15. The resource documents consist of the draft 10 CFR 60 flowdown report and section 8.4 of the SCP.

The assignment given to me on December 20, 1988, was to examine section 8.4.3 of the SCP and "review" section 3.0 and Appendices

C and D of Sandia report SAND85-0598. SCP section 8.4.3 (dated December, 1988) discusses potential impacts of site characterization activities on the repository postclosure performance objectives. Section 3.0 of Sandia report SAND85-0598 (dated December, 1988; authors: Fernandez, Hinkebein, and Case) examines whether the ESF enhances the potential for radionuclide releases during selected water flow scenarios. Appendix C contains a scenario describing fully saturated alluvial flow at the "old" exploratory shaft locations; and Appendix D contains additional information supporting the Appendix C analysis.

Three question categories were to be considered: category 1 examined whether the analyses contained in the SAND85-0598 were appropriate to determine how ES site characterization activities might affect conditions at the site; category 2 examined whether conclusions concerning how the changed conditions would affect postclosure performance were appropriate; and category 3 examined whether the same conclusions drawn in SCP Section 8.4 regarding the impact of the ESF on waste isolation were also clearly and directly presented in SAND85-0598. Please note that this assignment thus pertains to TAR review objective 1a above.

Review

Section 3.0 of SAND85-0598 evaluates whether possible water entry into the ES's and associated MPZ's (modified permeability zones created during shaft construction) could significantly enhance the radionuclide-release potential. The water source is the probable maximum flood (PMF) produced by either of two separate probable maximum precipitations, namely a local storm (thunderstorm) or a general storm.

The report evaluates various scenarios postulating water entry into the ES/MPZ's. One scenario examines whether either of the PMF's flowing down existing water courses can inundate the ES pad. Although somewhat unclear, the analysis appears to compare an "average" peak water height at a given channel cross section to the adjacent top of the ES pad. The analysis concludes that only peak flood discharges about 45 and 240 times greater than the thunderstorm discharge (the more severe of the two events) would reach the ES1 and ES2 collars, respectively.

To obtain the "average" peak water height, the analysis examines 5 channel cross sections along the length of the pad. For completeness, the analysis should state the water height at each cross section, along with its corresponding channel invert elevation.

The scope of the inundation study contained in SAND85-0598 does not address trends in topographical changes. Appendix C, however, determines the inundation and its results if the PMF were to occur sometime after an earth movement of sufficient magnitude to impound the entire flood discharge. Although the shaft-inflow results technically apply to the "old" ES locations (where saturated overburden contributed to the inflow), they could represent an upper bound case for the current ES locations. It seems to be a shortcoming that either 1) a similar analysis, including earth movement, was not performed for the current ES locations or 2) the SCP section 8.4 does not cite the appendix C study as an upper bound inflow case.

Other potential conflicts between SCP section 8.4 and SAND85-0598 section 3.0, Appendix C, and Appendix D are as follows: SAND85-0598 discusses how precipitate formation might effect ESF drainage capabilities, while no similar discussion appears in SCP section 8.4; SCP section 8.4 discusses how the separate issue of siltation might effect ESF drainage capabilities, while no similar discussion appears in SAND85-0598.

In all other respects, the analyses contained in SAND85-0598 appear valid. The range in theoretical conditions analyzed appears comprehensive. Assumptions and parameter selection appear reasonable and conservative. Conclusions appear appropriate.

cc: U.S. Geological Survey, Attenstion: MS-421 (L. Hayes), P.O. Box 25046, Denver CO 80225

Appendix K.2.3

**Letter from R. Trautz to W. E. Wilson, 12/22/88:
review of parts of sections 4.0 and 5.0
Fernandez et al. (1988)**

WBS: 1.2.3.3.6.2
QA: "N/A"

December 22, 1988

To: Bill Wilson, Technical Advisor

From: Rob Trautz, reviewer, Gaseous Phase Flow Project Chief RT

Subject: Review of Selected Analyses to Evaluate the Effect of the Exploratory Shafts on Repository Performance at Yucca Mountain, sections 4.0 and 5.0, by Fernandez and others (1988).

Fernandez and others (1988) determine the potential impact air movement through backfilled drifts, shafts, ramps or the disturbed zone surrounding these structures may have on gaseous phase radionuclide releases. Section 4.0 of their report deals with possible releases caused by air movement resulting from convective forces while section 5.0 looks at air movement resulting from barometric pumping. The authors determine the pneumatic conductivity of the shaft backfill material required in order for the effects of convection and barometric pumping to be minimized. I reviewed the aforementioned sections and summarize the findings by section as follows.

Section 4.0

1. Page 79, paragraph 1: A performance goal was established by the authors stating that air flowing through the shafts and their disturbed zones should not exceed 25% of the total flow of air from the repository. This seems to be an odd means of establishing a performance goal for gaseous radionuclide release rates. What concentration of C-14 and I-129 gases are present in the flowing air? Are the concentrations very high, below safety standards or non-detectable? If the contaminant concentrations are very high then one could be allowing a significant amount of gaseous radionuclides to reach the accessible environment based on the 25% total flow criteria.

2. I found that the authors utilized an appropriate model given by Hartman (1982, p.244, Equation [9-3]), but made the problem more difficult than it needed to be and less accurate by accepting the assumption that the gas is incompressible and dry (Appendix E, p.234 of authors' report). It is true that a 5% change in gas volume will result due to a change in pressure of 0.72 psi at atmospheric conditions (14.7 psia) as stated by the authors and Hartman (1982), but in the case of the repository the gas will undergo a 36% contraction as it rises up through the shaft. This can be demonstrated by utilizing the ideal gas law;

one mole of gas will occupy 31.8 liters at 115 C and 1 atmosphere, and only 23.4 liters at 13 C and the same pressure. This corresponds to volumes occupied by the gas at the ES bottom and top, respectively. Thus the utilization of equation (E-2), the equation of state for an incompressible fluid with constant volumetric thermal expansion (i.e. constant beta) in the authors' analysis, is inappropriate in this case. In addition, the authors have mixed two equations of state for the same fluid, that is, Hartman's Equation 9-3 (the authors' Equation [E-1]) was derived from the ideal gas equation which takes into account gas compressibility, and the authors' Equation (E-2) which is for an incompressible fluid with constant thermal expansion coefficient.

The mixing of equations of state in mid-analysis is not rigorous and has resulted in a poor estimate of the draft pressure calculated by the authors. The reviewer used Equation (9-5, p.244) in Hartman (1982) to calculate the natural ventilation head as follows:

p_1 = 87,111 Pa @ 1260 m altitude = 1819.4 lbf/ft^2
T_1 = 13°C = 55.4°F = 515.1 .R
T_2 = 23°C = 73.4°F = 533.1 .R
T_3 = 115°C = 239°F = 698.7 .R
T_4 = 13°C = 55.4°F = 515.1 .R
L = 314 m = 1030 ft
t_d = 73.4 - 55.4 = 18°F
t_u = 239 - 55.4 = 183.6°F
R = 53.35 ft-lb/lbm-.R

$$H_n = (2116.2/5.2)\ [(533.1/515.1)^{1030/(53.35)(18)} - (698.7/515.1)^{1030/(53.35)(183.6)}]$$

$$= 1.73 \text{ inches } H_2O\ (0.502 \text{ kPa})$$

This estimate of draft ventalation head is easily determined from the surface pressure (p_1, assumed to be 87,111 Pa by the reviewer), and temperatures at the top and bottom of the upcast and downcast shafts (T_1 - T_4, provided by the authors). In addition, Hartman's Equation (9-5) does not require that the gas behave as an incompressible fluid. The authors incompressibility assumption has resulted in a 20% (1.4/1.73/) underestimation of the draft ventalation head.

Neglecting the effect of water vapor on the draft head or pressure is also a poor assumption leading to a nonconservative estimate of air flow. The density of mine air saturated with water vapor is actually less than dry air (at the same temperature and pressure) thus requiring less energy to lift the same volume of gas. In addition, it is doubtful that the air would be perfectly dry even at elevated repository temperatures of 115 C. Near-field canister temperatures might be extremely high, but far-field cooler temperatures would help to moderate temperatures at the exploratory shaft. Under moderate conditions (60 C), mine or pore gas in equilibrium with free water in the pore space held by a tension of 100 bars would still have a relative humidity greater than 90%, and 50% for a 1000 bar tension. Thus the conservative approach would be to assume that the gas is 100% saturated at the repository temperature or at 100°C if virtual temperatures are employed.

Equation (9-5) in Hartman (1982) can also be used to determine the draft head when water vapor is present by substituting the virtual temperature for the absolute dry-bulb temperatures. Virtual temperature is the temperature which dry air must have at the given barometric pressure in order to have the same density as moist air at the same pressure, given temperature, and mixing ratio (List, 1968). The mixing ratio is simply the mass of water vapor to mass of dry air in the gas mixture. Virtual temperatures were calculated by the reviewer using Equations (18) and (19) on page 297, and Tables 72 and 73 in List (1968). Saturated mixing ratios (r_w) cannot be determined for temperatures above 100 C, so this temperature was used to reflect repository conditions. A saturated mixing ratio at 100 C was calculated from the mass of vapor and mass of dry air in the mixture at this temperature (American Gas Association, 1966, p.1/25, Table 1-27). Virtual temperatures, relative humidities and pressures used to calculate the draft head are summarized below.

p_1 = 87111 Pa = 1819 PSF
T_{v1} = 13.19 C @ 87.111 kPa and 10% relative humidity
T_{v2} = 79.99 C @ 87.111 kPa and 100% relative humidity
T_{v3} = 325.8 C @ 101.595 kPa and 100% relative humidity
T_{v4} = T_{v1}

Converting these values to the appropriate engineering units for use in Equation (9-5) of Hartman (1982) and performing the computations results in a draft head of 4.1 inches of water (1021 Pa). This value is nearly three times higher than that estimated by the authors and thus the authors' assumption that a dry gas analysis leads to a conservative approach is incorrect. It should be noted that even the reviewers analysis using virtual temperatures may be oversimplistic due to the fact that condensation will take place as the moist saturated air rises in the shaft and cools making the analysis more complicated.

The reviewer does not have access to the resistance model utilized by the authors to determine the pneumatic conductivity of the backfill material required to minimize airflow. Thus it is not possible for the reviewer to determine the pneumatic conductivity of the backfill based on his recalculated draft heads. One thing is certain, an increase in draft head over that reported by the authors will require a decrease in the pneumatic conductivity in order to maintain the same flow rate.

Section 4.0 Summary

In conclusion, the reviewer feels the authors have not taken a conservative approach to estimating the draft pressures needed to calculate the conductivity of the backfill material required for minimizing convective airflow. A higher value of the draft pressure was otbtained by the reviewer (25 to 300% higher than the authors') when the effects of gas compressibility and water vapor transport were included. Under-estimating the draft pressure will result in overestimating the pneumatic conductivity for the same flow rate; that is, the pneumatic conductivity of the backfill needs to smaller than that reported by the authors based on the reviewers analysis. The reviewer cannot determine how much smaller the conductivity should be because he does not have access to the resistance model used by the authors; however, the reviewer recommends that further model runs be performed by the authors in order to take into account compressibility and water vapor effects. These results should then be summarized in Section 8.4.3.2.1.4 of the SCP (p. 8.4.3-21) if they differ significantly from the authors' previous conclusions.

Section 5.0

The effects of barometric pumping and its ability to displace air or induce airflow through backfilled shafts or drifts was analyzed in section 5.0 of Fernandez and others (1988). The conceptual (analytical) model used by the authors was found to be appropriate. The boundary conditions of a relatively low frequency, low amplitude storm, a high frequency, high amplitude, torando and a very low frequency, low amplitude seasonal change in barometric pressure were found to be appropriate, but possibly too simplistic. The barometric signature often has several periodic events superimposed on one another over the same period of time. For instance, diurnal and semi-diurnal pressures can be superimposed on barometric high or lows caused by storm fronts which can be superimposed on a seasonal barometric pressure trend. Decomposing the barometric signature into seperate events makes the analysis simpler but may underestimate the effect of barometric pumping if the events are additive. The reviewer feels that the conclusions drawn by the authors are probably adequate based on the fact that convective airflow due to elevated repository temperatures appears to be the dominate driving force.

Review References

American Gas Association, Gas Engineers Handbook, 1st edition, 2nd printing, The Industrial Press, 1966.

Hartman, H.L., Mine ventilation and air conditioning, 2nd edition, John Wiley and Sons, Inc., 1982.

List, R.J., Smithsonian Meteorological Tables, 6th revised ed., 4th reprint, Smithsonian Institution Press, 1968.

CC: Barney Lewis

DRY BULB TEMPERATURE CALCULATIONS

R. TRAUTZ
12/21/83
USGS

$T_1 = 13°C = 55.4°F \ (515.1\ °R)$

$T_2 = 23°C = 73.4°F \ (533.1\ °R)$

$T_3 = 115°C = 239°F \ (698.7\ °R)$

$T_4 = 13°C = 55.4°F \ (515.1\ °R)$

$\Delta t_d = 73.4 - 55.4 = 18\ °F \qquad \Delta t_w = 183.6\ °F$

$$\Delta H_n = 349.8 \left(\left(\frac{533.1}{515.1} \right)^{1030/53.35(18)} - \left(\frac{698.7}{515.1} \right)^{1030/53.35(183.6)} \right)$$

$$= 349.8 \left((1.0349)^{1.07258} - (1.3564)^{0.10515} \right)$$

$$= 349.8 \left(1.03753 - 1.032577 \right)$$

$$= 349.8 \left(0.00495 \right)$$

$$= 1.73 \text{ in } H_2O \quad (431\ Pa)$$

VIRTUAL TEMPERATURE CALCULATIONS

K. TRAUTZ
12/22/88
USGS

212°F = 100°C

MIXING RATIO @ 100°C = 37.32 $\frac{\text{lbm of Vapor}}{\text{MCF}}$ / 0.158 $\frac{\text{lbm of dry air}}{\text{MCF}}$ = 236.2 = r_w

The saturated virtual temperature increment

$$= (T_v - T)_w = T r_w \left(\frac{1}{0.62197} - 1\right)\left(\frac{1}{1 + r_w}\right)$$

$$(T_v - T)_w = 373\,°K\,(236.2)\left(\frac{1}{0.62197} - 1\right)\left(\frac{1}{1 + 236.2}\right)$$

$$= 225.8\ °C$$

$\therefore\ T_{v\,100°C\ @\ 100\%\ RH} = 273 + 100 + 225.8 = 598.8\,°K\ (325.8\,°C)\ (618.4\,°F,\ 1078.1$

$T_{v\,23°C\ @\ 100\%\ RH\ \text{and}\ 870\,mb} = 273 + 23 + 3.66 = 299.66\,°K\ (26.66\,°C)\ (79.99\,°F,\ 539.7\,°R$

$$T_{v\,13°C\ @\ 10\%\ RH\ \text{and}\ 870\,mb} = 0.1(1.87) + 0.1(1-0.1)\left(\frac{0.01093}{1+0.1(0.01093)}\right)(1.87) + 13 + 273$$

$$= 0.187 + 0.001837 + 13 + 273$$

$$= 286.2\ °K = 13.188\ °C\ \ (55.74\,°F,\ 515.4\,°R)$$

$\Delta T_a = 79.99 - 55.74 = 24.25\ °F \qquad \Delta T_a = 562.66\ °F$

HARTUN (9-E

$$\Delta H_a = \frac{1319}{5.2}\left(\left(\frac{539.7}{515.4}\right)^{1030/5335(24.25)} - \left(\frac{1078.1}{515.4}\right)^{1030/5335(\cancel{24.25})\ 562.7}\right)$$

$$= \frac{1319}{5.2}\left((1.0471)^{0.79614} - (2.09177)^{0.03431}\right)$$

$$= 349.8\,(1.03735 - 1.025645)$$

$= 4.1$ in H_2O (1021 Pa)

K.2-17

Appendix K.2.4

Letter from S. G. Doty to W. E. Wilson, 12/28/88:
review of West (1988)

Science Applications International Corporation
An Employee-Owned Company

December 28, 1988

D. Gillis 1-3-89

WBS: 1.2.3.3.6.2
QA: "QA"

W.E. Wilson III
Yucca Mountain Project Branch
U.S. Geological Survey
P.O. Box 25046, MS-421
Denver Federal Center
Lakewood, Co 80225

Subject: Review of West (1988)- NNWSI ESF Fluids and Materials Evaluation

Dear Bill:

In West (1988), a study was conducted to determine if any fluids or materials used in the Exploratory Shaft Facility will make the mountain unsuitable for future construction of the repository. The study consisted of compiling a data base of all fluids/materials to be used in the ESF and evaluating the impact by a decision tree analysis approach. Also, as part of the report, evaluations were made of the amount of water that will be lost during the excavation of the shaft, the distance the water will travel into the side walls of the shaft, and the amount of radionuclide movement caused by microorganisms. These evaluations were made by reviewing reports published by other NNWSI participants. For example, to evaluate water transport, reports by Klavetter and Peters (1987), Bodvarsson et al (1987), Eaton and Peterson (1987), Fernandez et al (1988), Daily and Ramirez (1987), and Kwicklis and Hoxie (1987) were evaluated. These reports were briefly summarized in the text (1 or 2 paragraphs), and in general, did not include enough information on input data, assumptions, boundary conditions, etc. to evaluate the accuracy of the results. Based on the results of these reports, West made conclusions and recommendations; some of which were referenced in the SCP. In the following paragraphs, I have summaried the findings of my review.

1. Based on reports by F&S, SNL, and REECo, West concluded that a value of 10% should be selected for the amount of drilling fluid that will be lost to the surroundings as a result of shaft excavation and drifting. This does not appear to be a conservative value based on the information provided on pages 128-131 of her report. For example, it is stated that F&S's borehole logs of G-4 suggest that an average figure of over 70% fluid loss is more correct than 10%. F&S's evaluation of fluid loss during drifting is only as low as 10% when drifting downward at a steep grade (-8%). When drifting upgrade, F&S stated that the fluid loss could be higher than 50%. Coppages' estimates of drilling fluid loss are unsubstantiated in West (1988), and could only be evaluated by going back to the reference; however, West does include Coppages recommendations on how to reduce fluid losses. His suggestions seem reasonable except for "avoid drilling into fractures". Roger Zimmerman's evaluation assumes a rock mass acceptance of 7% which is unsubstantiated in West's summary of his work. A review of his calculations would be required to evaluate his conclusion. In any

1626 Cole Boulevard, Su... ..., C...orado 80401 (303) 231-9094
Other SAIC Offices: ...uquerque, Boston, Colorado Springs, Dayton, Huntsville, Las Vegas, Los Angeles, McLean, Oak Ridge, Orlando, Palo Alto, San Diego, Seattle, and Tucson

event, it does not appear that anyone has modeled the problem; and thereby, taken into account the effects of a range of aperture distributions, matrix imbibition, etc.

2. Based on a review of water transport reports, West concluded that "the water would not penetrate very far". This is probably true for the matrix but not necessarily for the fracture system. Based on fracture-matrix modeling, Kwicklis and Hoxie (1987) point out that the distance the water may travel within the fractures depends on the imposed boundary head and on the largely unknown hydraulic properties of the fractures. They conclude that "although the introduction of drilling fluids may not produce a significant impact locally on the matrix in situ condition, a pronounced effect could be produced within a hydraulically well-connected fracture system."

   Despite her conclusion that water will not penetrate very far, West takes a conservative approach in her recommendations on the water transport issue by supporting the USGS position that: (1) dry mining techniques should be used for the rooms and adjacent portions of the access drifts within 100 ft from the center of either room and (2) minimal-water techniques should be used in the excavation of any underground opening that falls within a spherical radius of 300 ft from the center of the Bulk K room. However, this should be updated to use minimal-water techniques throughout the main level since four locations are now planned for the Bulk K Test and the exact locations can not be determined until after excavation (after the fracture system is exposed).

3. The results of the decision tree analysis identified hydrocarbons and solvents as the only two major categories which could have potentially significant effects on location suitability. West points out that interactions between hydrocarbons and solvents will tend to lower the viscosity of liquid hydrocarbons, enabling them to be carried deeper into the formation. "However, based on hydrological analyses, West predicts that the depth of penetration will not amount to more than a few centimeters" (quoted from SCP). This quote is only true if the fracture system is not taken into account, as discussed in comment 2. West concludes that the use of hydrocarbons and solvents should be restricted, which is an appropriate conclusion having taken into account the fracture system.

Sincerely,

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

S. G. Doty
cc: R. L. Wise, SAIC-Golden
    T. G. Barbour, SAIC-Golden
    Project File: 527-32-1-1

Appendix K.2.5

Work requests for Interactive Graphics Information System submitted by S. Sinnock, received 11/10/88 and 12/20/88

WORK REQUEST

Send to:
TECHNICAL DATA BASE ADMINISTRATOR
SANDIA NATIONAL LABORATORIES
GEOSCIENCE ANALYSIS DIVISION.6315
P.O.BOX 5800
ALBUQUERQUE,NM 87185
PHONE:(505 OR FTS)846-4922

REQUEST NUMBER: 250
DATE RECEIVED: 11/10/88
PRODUCT QA LEVEL: Q1
DATA QA LEVEL: Q3

TO BE COMPLETED BY REQUESTOR

NAME: Scott Sinnock	SIGNATURE: [signature] DATE: 11/7/88
ORGANIZATION: 6317 SNL	DIVISION: 6317
ADDRESS: 101 Convention Ctr. Dr. Suite P230 Las Vegas	TELEPHONE: 702-794-7200 FTS 544-7200

TO BE COMPLETED BY DATA BASE PERSONEL

TYPE: ☐ DATA ENTRY (FORM # ______) ☒ PRODUCT REQUEST ☐ AUDIT ☐ OTHER

ACCEPTED BY: [signature]	DATE: 11/9/88
ASSIGNED TO: Samuel R. Hingle	DATE: 11/10/88
VERIFIED BY: Samuel R. Hingle	DATE: 11/23/88
APPROVED BY:	DATE:

WORK REQUESTED - ATTACH ADDITIONAL EXPLANATIONS, SKETCHES AND EXAMPLE LISTINGS, IF APPROPRIATE:

REQUESTED QA LEVEL: ~~3~~ 1

For the 5 locations in Nev. Coordinates ~~N E~~
~~N E~~ see
~~N E~~ attached
~~N E~~ for boundaries
N E of 5 zones
of site

The following products, based on Groundwater Travel Time Calculations for EA (Jos 99)

1) Histogram, Mean, Standard Deviation and Range of Travel Times to the water table based on 10 ft thick elements ~~and for~~ and 100 Monte Carlo iterations for 0.1, 0.5, and 1.0 mm/yr flux

2) Thickness of each unit (TSw2+TSw3; CHnv, CHnz, PPw, PPn, BFw, BFn) below design repository and above water table (in meters)

3) Total thickness of zeolite zones above the water table (in meters)

Note: for support of ESF/SCP/Design Control Issue Paper - requested date of completion 11/9/88 - FAX results to requester (OVER)

PRODUCT NUMBERS, OR ACCESSION NUMBERS.

1) CAL0260, CAL0261, CAL0262, CAL0263, CAL0264, CAL0265, CAL0266
3) CAL0267

ORIGINAL - JOB LOG
COPY TO - REQUESTOR
FILE - 6310 4_/121S_/JLG/QI

FORM BCWMOD:WORKREQ.M2

Table 9. Coordinates of Preferred Areas and Sites

VERTICES	NEVADA COORDINATE SYSTEM (feet) EAST	NORTH
AREA 1		
A	558857	764541
B	558703	763430
C	559565	764908
D	559528	764977
E	559609	765178
F	559541	765511
G	559442	765518
Site	559100	764300
AREA 2		
A	559768	770284
B	559173	768505
C	559099	768463
D	558834	768445
E	558960	768617
F	559196	769285
G	559331	769777
H	559520	770348
Site	559600	770300
AREA 3		
A	563008	764338
B	562987	764116
C	563101	764075
D	563221	764311
Site	563100	764100
AREA 4		
A	563245	766351
B	563178	765583
C	563610	765825
D	563728	765798
E	563850	766221
F	563781	766292
Site	563300	766000
AREA 5		
A	561597	767922
B	561671	768210
C	561716	768190
D	561646	767914
Site	561653	768046

TO BE COMPLETED BY REQUESTOR		REQUEST # 260
NAME: Scott Sinnock	SIGNATURE: Scott Sinnock	DATE: 12/20/88
ORGANIZATION: SNL/LV	DIVISION: 6317	
ADDRESS: 101 Convention Center Dr. Suite P-230	TELEPHONE: FTS 544-7200	

TO BE COMPLETED BY DATA BASE PERSONNEL

TYPE: ☐ DATA ENTRY (FORM # ________) ☒ PRODUCT REQUEST ☐ AUDIT ☐ OTHER

ACCEPTED BY: C. A. Pantano	DATE: 12/20/88
ASSIGNED TO: Samuel R. Dengler	DATE: 12/21/88
VERIFIED BY: Samuel R. Dengler	DATE: 1/18/88
APPROVED BY:	DATE:

WORK REQUESTED - ATTACH ADDITIONAL EXPLANATIONS, SKETCHES AND EXAMPLE LISTINGS, IF APPROPRIATE: REQUESTED QA LEVEL: QI

(SEE ATTACHMENT)

REQUEST NUMBER 260
DATE RECEIVED 12/21/88
PRODUCT QA LEVEL Q1
DATA QA LEVEL Q3

PRODUCT NUMBERS, OR ACCESSION NUMBERS:

CAL0305, CAL0306, CAL0307, CAL0308, CAL0309, CAL0310
CAL0311, CAL0312, CAL0313, CAL0314, CAL0315, CAL0316
CAL0317, CAL0318, CAL0319, CAL0320, CAL0321

APPROVALS:	
DATA BASE OPERATOR:	DATE:
DATA BASE MANAGER:	DATE:
REQUESTOR:	DATE:

ORIGINAL - [illegible]
COPY TO - REQUESTOR
FILE - [illegible]

FORM [illegible]

PAGE 1 OF __

DEC-21-'88 14:48 ID:USGS-NNWSI/LAS VEGAS TEL NO:7027947090+8547090 #363 P02

ATTACHMENT TO IGIS WORK REQUEST

Call# 0199

Requestor: Scott Sinnock 12/20/88
Work Requested:

For the rectangular area bounded by the following Nevada Coordinates:

N 772500	E 556250
N 755000	E 556250
N 755000	E 566250
N 772500	E 566250

Please provide the following maps with (a) the perimeter drift of the repository and (b) the 5 areas of alternative ESF areas from Bertram, 1984, (SAND 84-1003, page 73) highlighted by appropriate line weights and/or shading (light shading of 5 alternative ESF locations only)

CAL0305 ✓ * 1. Isopachs of thickness between repository floor and base of TSw2 REF 0235
306 ✓ 2. Isopachs of thickness between base of TSw2 and base of TSw3 REF 0237
307 3. Isopachs of thickness between base of TSw3 and planar surface Tzz
308 4. Isopachs of thickness between planar surface Tzz and base of CHn3 TRUNCATED BY WATER TABLE REF 0240
309 ✓ 5. Isopachs of thickness between base of CHn3 and Base of PPw, truncated by water table REF 0265 REF 0011
310 ✓ 6. Isopachs of thickness between base of PPw and Base of CFUn, truncated by water table REF 0018 CFUn ? REF 0011
311 ? 7. Isopach of thickness between base of BFUn and base of BFw, truncated by water table — REF 0012 — SEE CHRIS REF 0284
312 8. Isopachs of thickness between base of BFw and the water table REF 0242
313 * 9. Isopachs of combined thicknesses of items 1, 2, 4, 6 and 8 (these)
314 ? 10. Isopachs of combined thicknesses of items 3, 5 and 7
315 11. Isopachs of thickness of Zeolitic Zone between Tzz and water table - See Chris
316 ✓ *12. Isopachs of thickness between repository floor and water table
317 *13. Isopachs of thickness between repository floor and ground surface
318 ~~14~~. Location of surface fault traces (from CAL 0126); note: delete dashed boundary of "primary exploration block" shown in CAL 0126
319 15. Surface Topography contours CAL 030
320 16. Structure contour map of the base of TSw3 CAL 013 → CHn1

Distance [illegible] from [illegible] [illegible]

DEC-21-'88 14:48M ID:USGS-H#USI/LAS VEGAS TEL NO:702794090+8547090 #363 P03

321 17. Also please provide a table of the following information for each of the following five sites

	E	N
Site 1	559100	764300
Site 2	559600	770300
Site 3	563100	764100
Site 4	563300	766000
Site 5	561653	768046

	Site 1	Site 2	Site 3	Site 4	Site 5
Thickness of TSw2(3)					
Thickness of TSw3					
Thickness of CHnz					
Thickness of CHnz					
Thickness of PPw					
Thickness of PPn(1)					
Thickness of BFw					
Thickness of BFn(2)					
Thickness of Zeolites					
Thickness of Unsaturated zone					
Thickness of Repository Overburden					

(1) PPn = CFUn in RIB
(2) BFn = CFMn in RIB
(3) TSw2 thickness is only below repository floor

DEC-21-'88 14:48M ID:USGS-NNWSI/LAS VEGAS TEL NO:7027947090*85447090 #363 P04

Notes:

(1) All thicknesses are for unsaturated rocks only, i.e. above the water table

(2) For items with asterisk
"Repository Floor" elevation must be extended to site 2 (Bertram, 1984, N 770300, E 559600) the following method is suggested:

Thickness from Repository floor to base of TSw2 (divided by)
Total thickness of TSw2 at the closest or approximately closest point on the perimeter drift to site 2

(Times) the Total thickness of TSw2 at site

(Note, elevation of "repository floor" at site 2 is then elevation of base of TSw2 plus thickness calculated by method above)

(3) Thermal/Mechanical unit designators are from RIB. Ch.1 Sec. 1, Item 1, page 2 of 4, version 4, revision 0, 11/28/88

DEC-21-'88 14:48M ID:USGS-NNWSI/LHS VEGAS TEL NO:7027947090•85447090 #363 P05

Appendix K.2.6

Letter from C. A. Rautman to S. Sinnock, 1/17/89: IGIS products

Sandia National Laboratories
Albuquerque, New Mexico 87185

January 17, 1989
WBS: 121
QA

Scott Sinnock
Sandia National Laboratories
101 Convention Center Drive; Suite P230
Las Vegas, Nevada 89109

Subject: IGIS Products, Exploratory Shaft Locations (Job 260)

Dear Scott:

Enclosed are seventeen (17) products representing the several items described in your work request dated December 20, 1988. The following table matches CAL product numbers against specific requests.

CAL No.	Item	CAL No.	Item	CAL No.	Item
0305	1	0311	7	0317	13
0306	2	0312	8	0318	14
0307	3	0313	9	0319	15
0308	4	0314	10	0320	16
0309	5	0315	11	0321	17
0310	6	0316	12		

Product CAL0321 is a printout that contain the requested thicknesses of various stratigraphic entities at each of the five Exploratory Shaft locations taken from the Bertram (1984) SAND report. These thicknesses are extracted directly from the other referenced CAL products.

As you know, the IGIS models contacts between rock units as surfaces. The surface topography, the top of prevalent zeolites and water table are additional surfaces that may cross-cut unit contacts. In general, the surfaces used to construct a given product are described in algebraic format on each product. For example, item 12 (CAL0316) was constructed by taking the surface representing the elevation of the repository floor and subtracting the surface representing the elevation of the water table. In some cases, it was necessary to use the higher (or lower) of two surfaces, as is the case where the water table cross-cuts a particular unit's lower contact. These are indicated by the functional notation "higher(surface 1 or surface 2)."

Constructing the "floor of the repository" outside of the limits of the underground facility posed a serious problem, as the concept of describing a man-made feature somewhere where that feature simply does not exist is somewhat of an oxymoron. The surface representing the "floor of the repository" extrapolated to regions outside the limits of the design repository is thus somewhat suspect. In addition, all derived surfaces or thicknesses that use the "floor of the repository" are suspect in the region outside those limits.

It was not possible to develop a rigorous algorithm to locate the repository horizon outside the repository in the manner suggested by your work request attachment because the repository itself has been engineered at different levels within the Topopah Spring welded unit. Instead, we have simply "extended" the actual repository floor using the triangulation algorithm developed by Lane Yarrington. Although this may be a fairly acceptable method close-in to the repository itself, at some distance away the extrapolation will become completely meaningless (and may, in fact, be misleading). The only ESF location affected by this problem is Area 2. Area 2 probably is sufficiently close to the "real" repository that the extrapolation is not grossly in error. We note that had the Exploratory Shaft been placed in Area 2, the entire design of the repository most likely would have been different.

We trust that you will find these products satisfactory, given that we have iterated informally several times. If they are not, we will be pleased to work with you to revise them. Should these products be included in a document of some type, we remind you that traceability for quality assurance purposes is by means of the CAL product number.

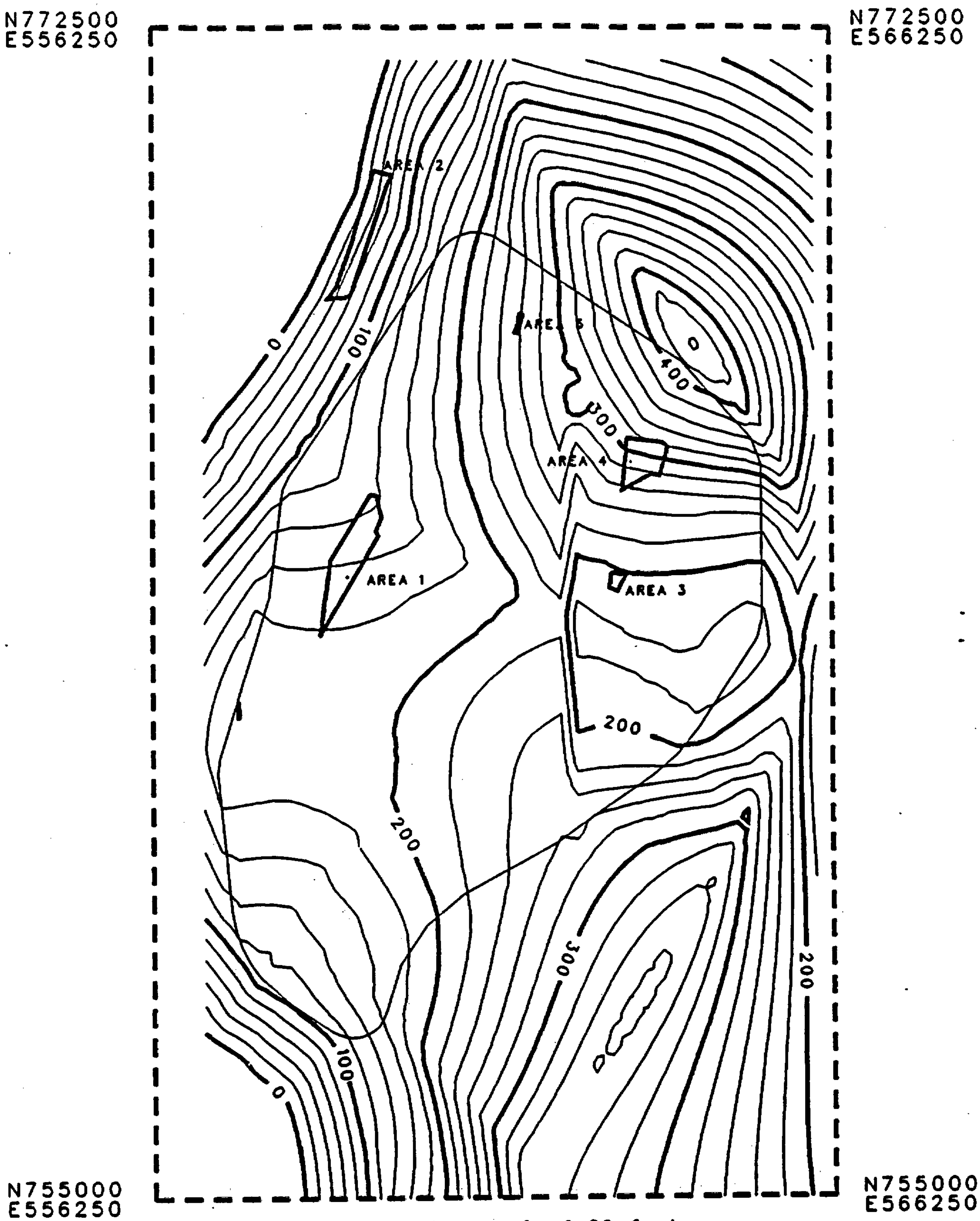
Best regards,

Chris

Christopher A. Rautman
Geoscience Analysis Division 6315

enclosures: as stated

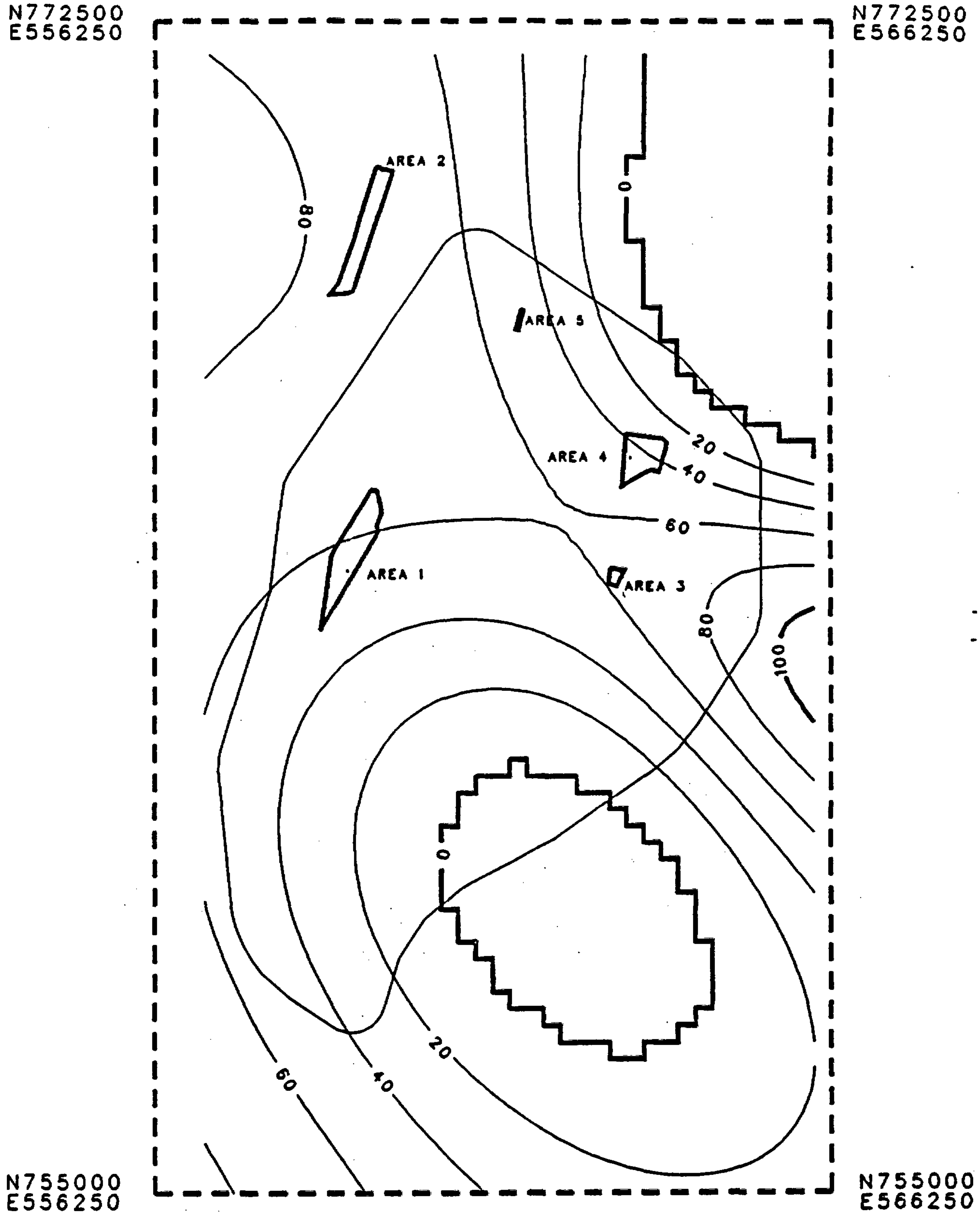
copy to:
6310 J. E. Stiegler
6315 L. E. Shephard
6315 S. Dengler
6315 C. A. Rautman
6310 43/12132/COR/Q1
6310 43/12132/JLG-260/Q1
YMP CRF



Contour interval of 20 feet

Thickness of Unit TSw2
Below the Repository Floor

Thickness = Repository Floor - TSw2 **CAL0305**

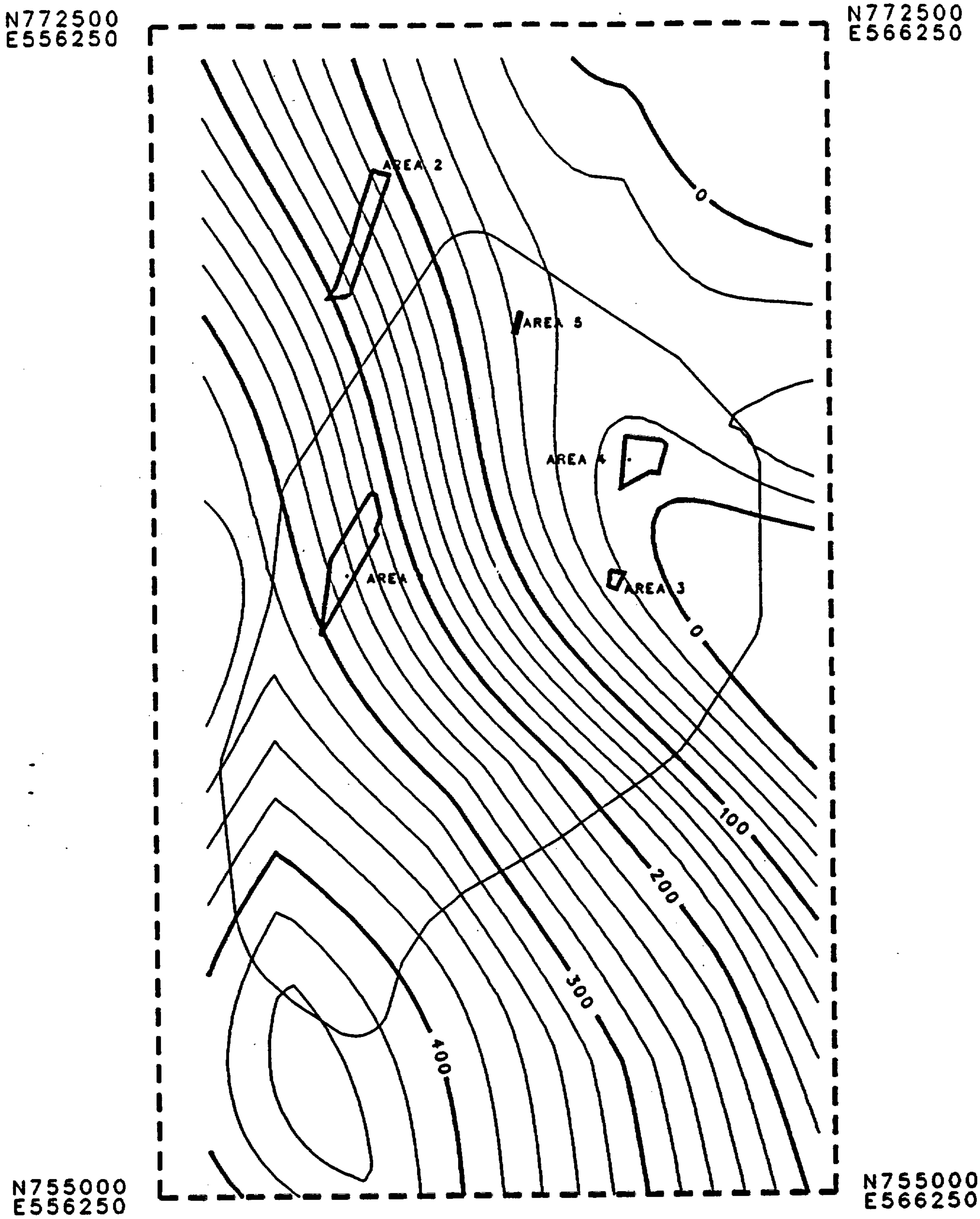


Contour interval of 20 feet

Thickness of Unit TSw3 (Vitrophyre)

Thickness = TSw2 - TSw3

CAL0306

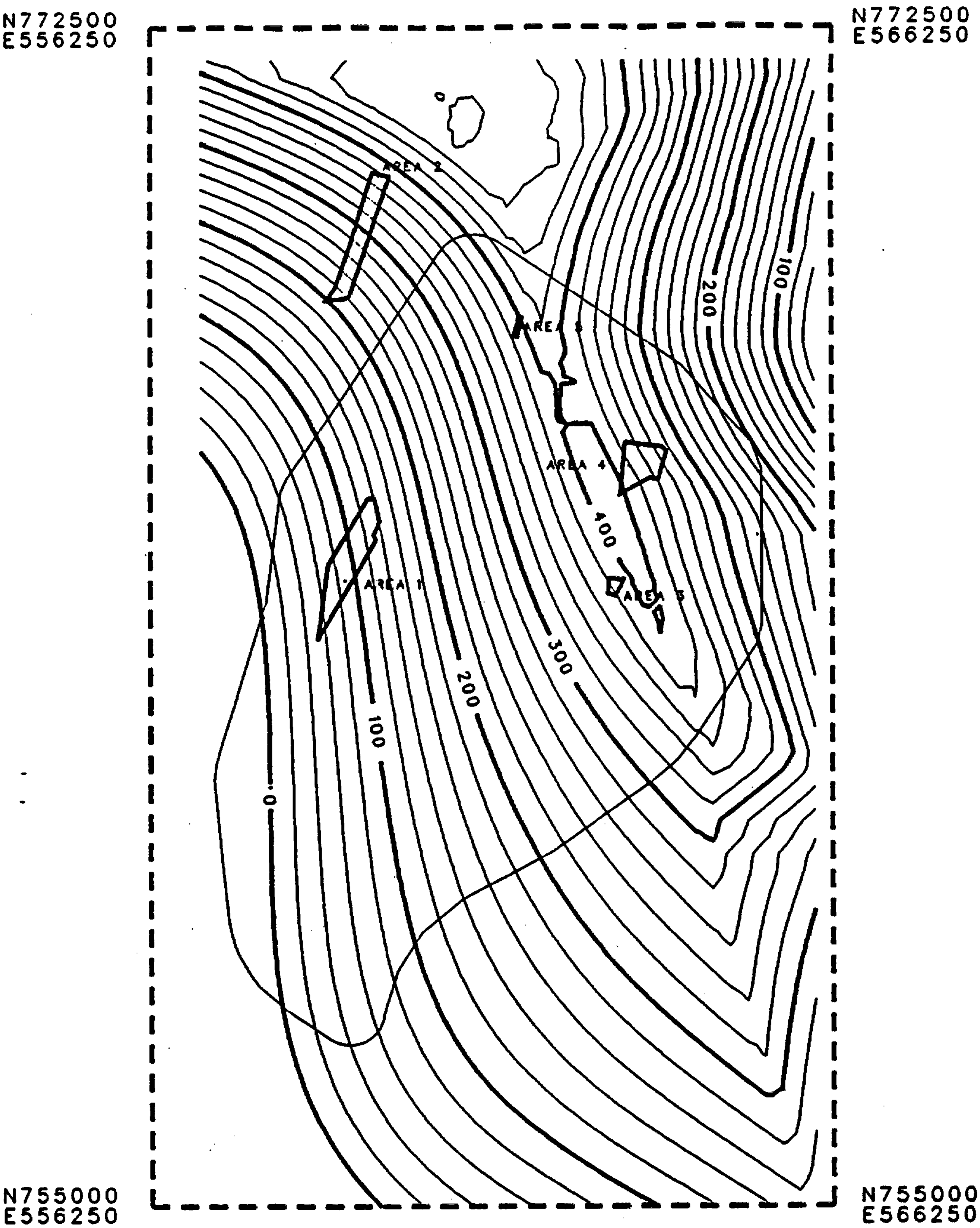


Contour interval of 20 feet

Thickness of Unit CHnv

Thickness = TSw3 - Higher (TZZ or CHn3)

CAL0307

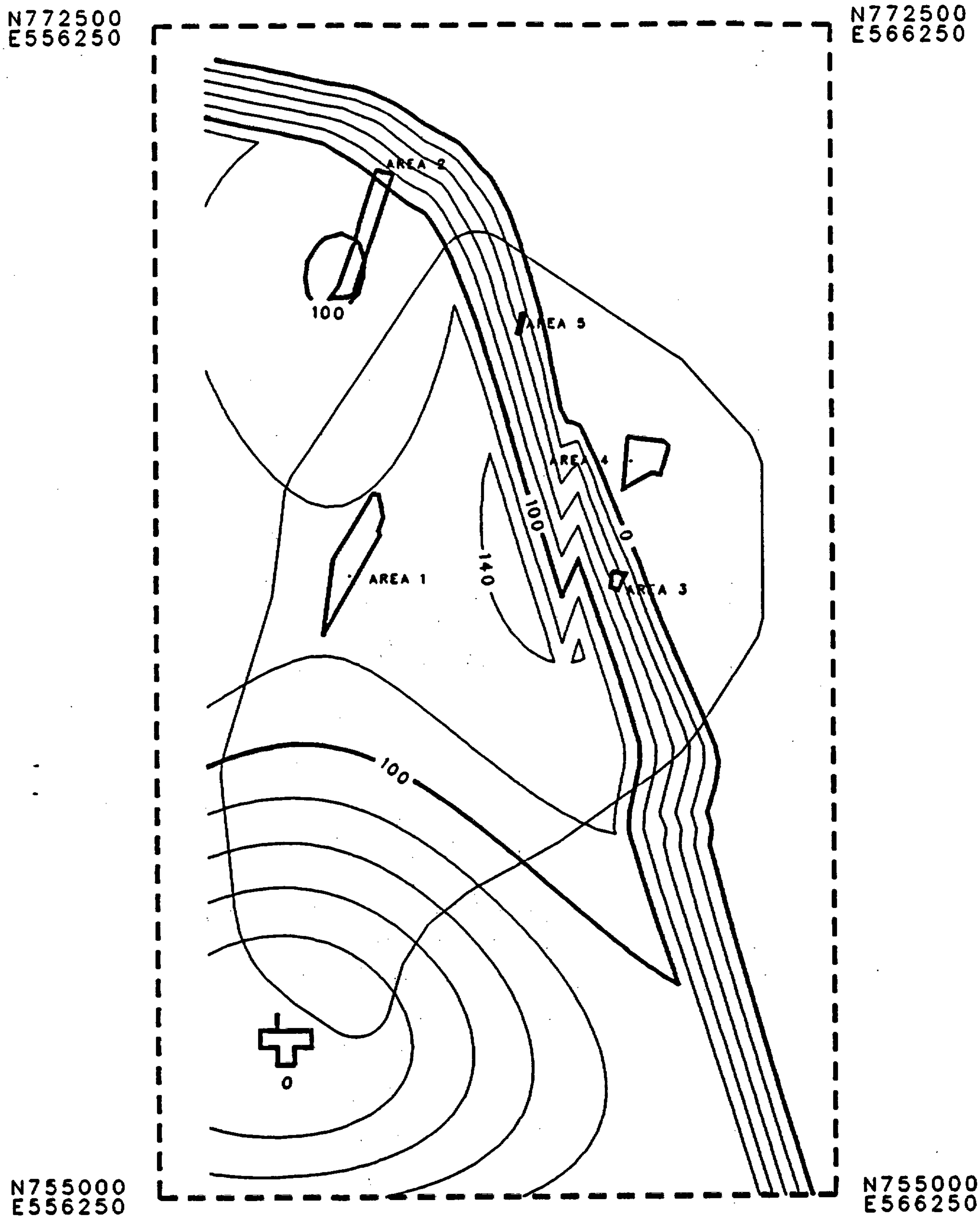


Contour interval of 20 feet

Thickness of Unit CHnz Above the Water Table

Thickness = Lower (TZZ or TSw3)
- Higher (CHn3 or Water Table)

CAL0308

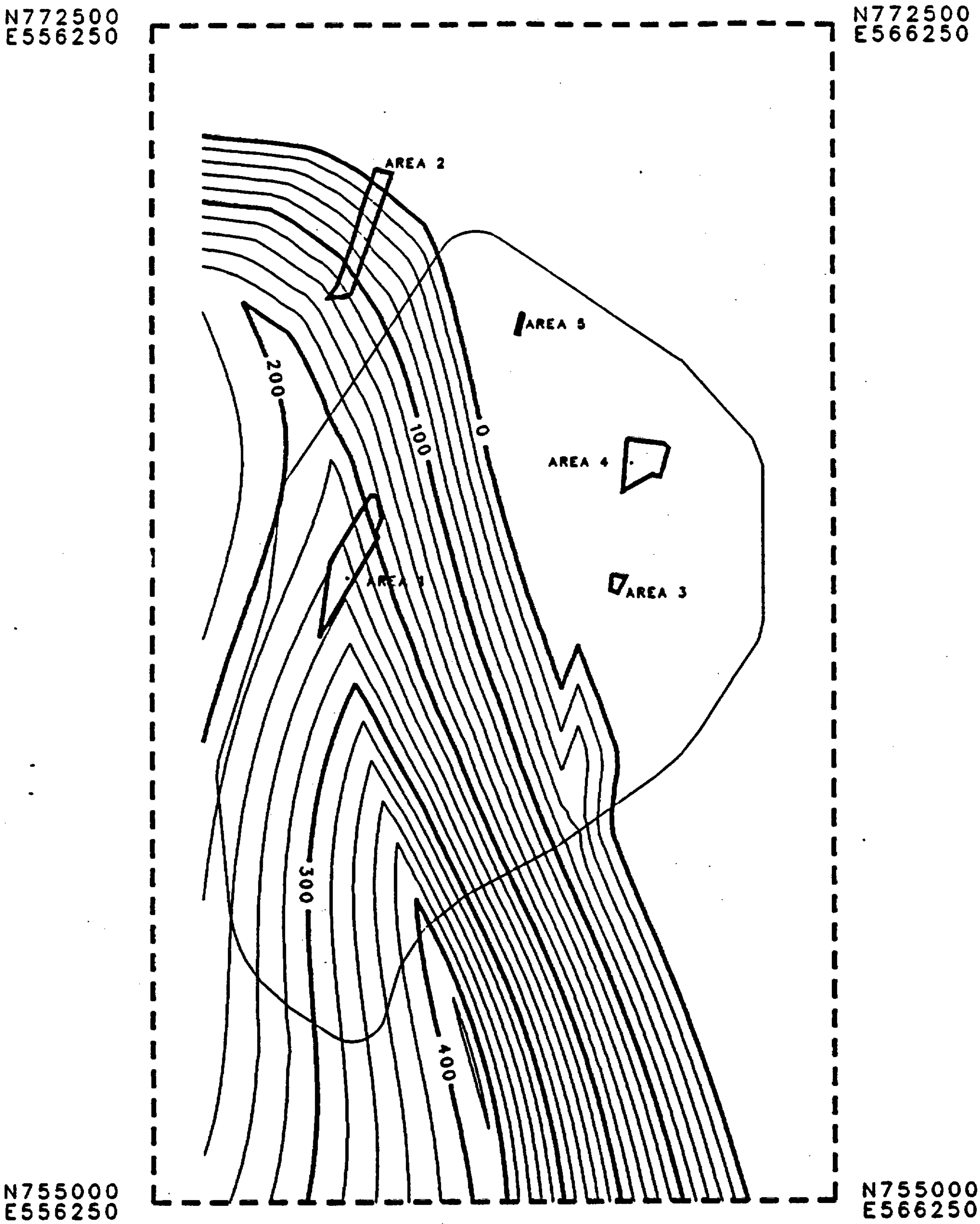


Contour interval of 20 feet

Thickness of Unit PPw Above the Water Table

Thickness = Higher (CHn3 or Water Table) - Higher (PPw or Water Table)

CAL0309

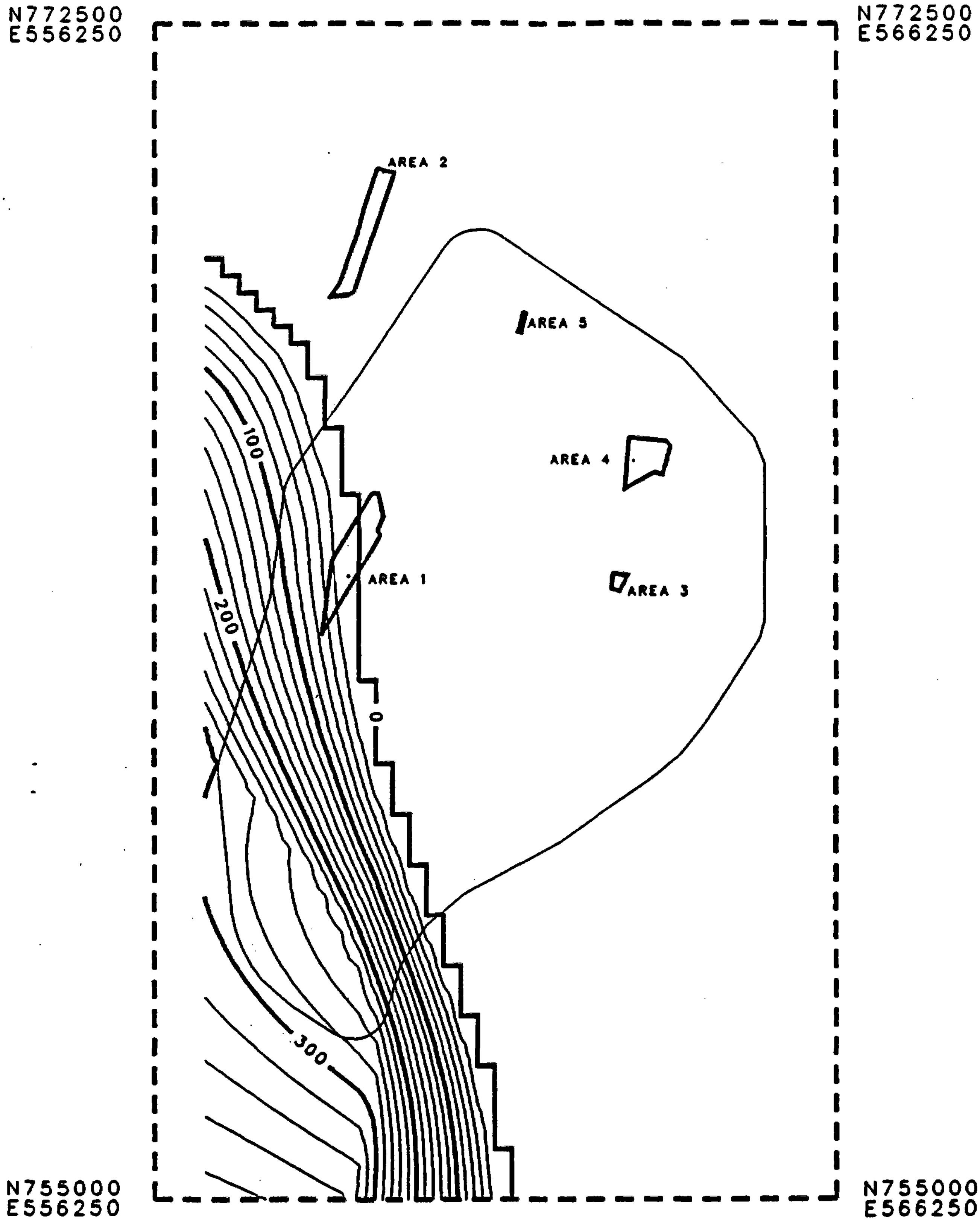


Contour interval of 20 feet

Thickness of Unit CFUn Above the Water Table

Thickness = Higher (PPw or Water Table) - Higher (CFUn or Water Table)

CAL0310

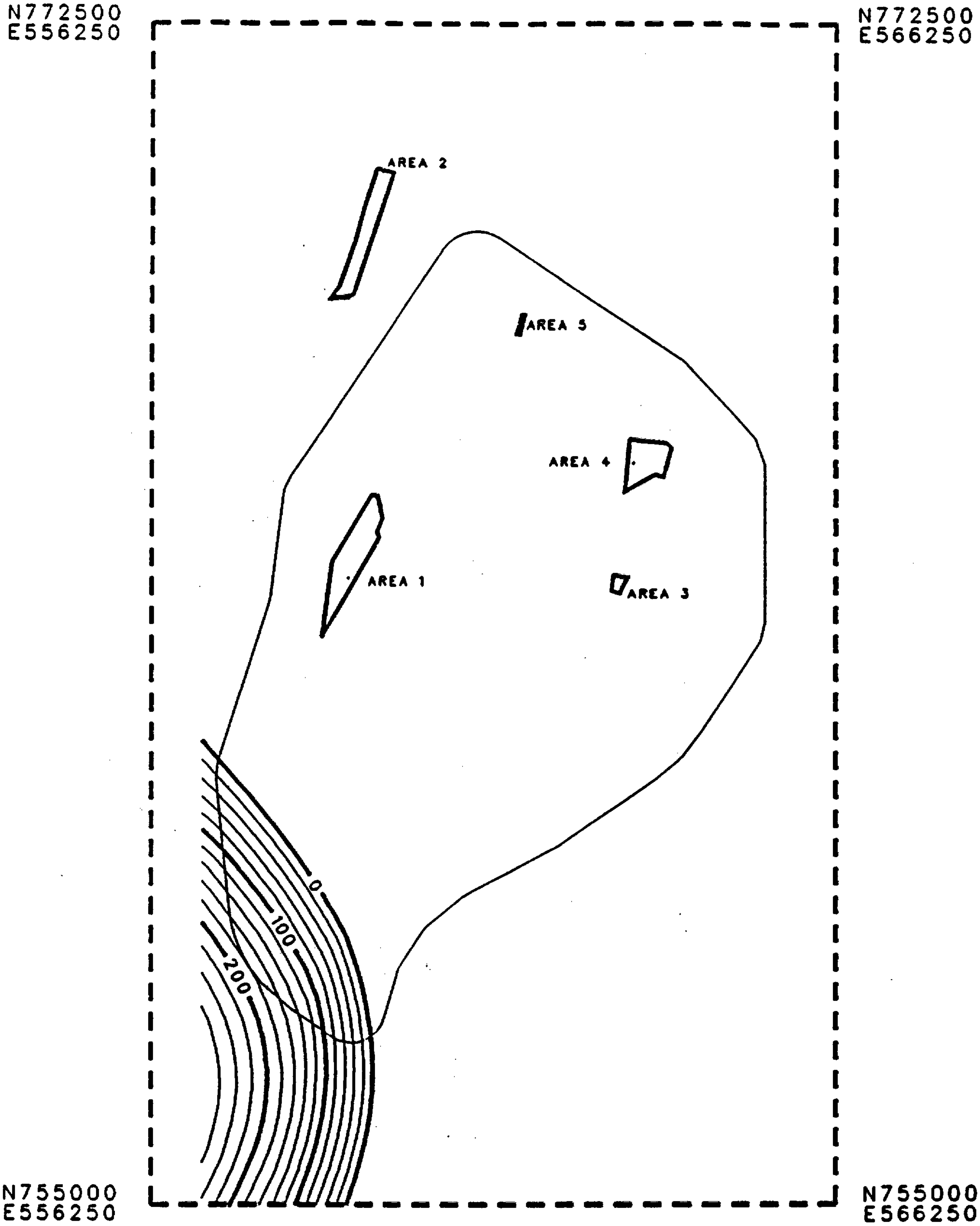


Contour interval of 20 feet

Thickness of Unit BFw Above the Water Table

Thickness = Higher (CFUn or Water Table) -
Higher (BFw or Water Table)

CAL0311

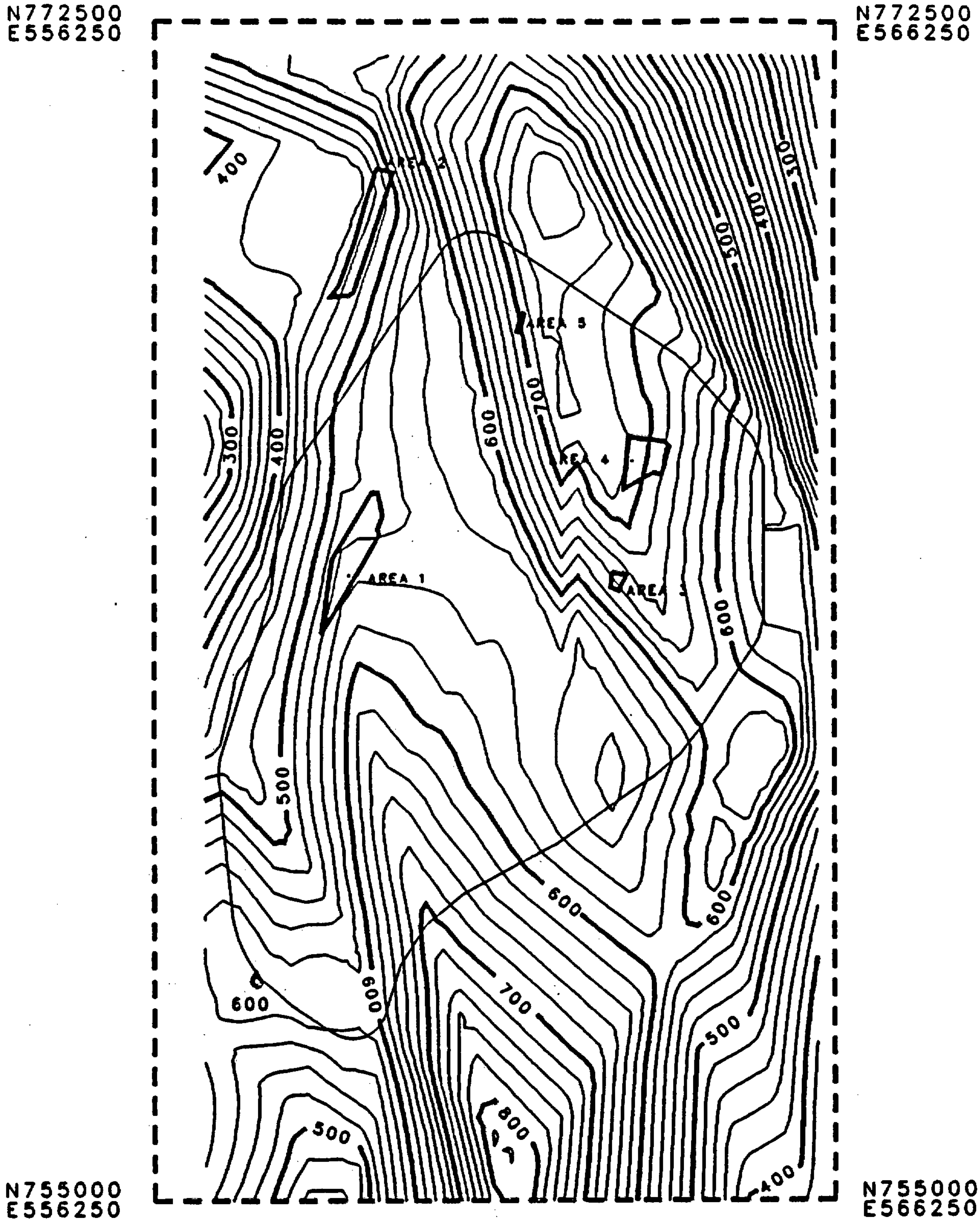


Contour interval of 20 feet

Thickness of Units Below Unit BFw and Above the Water Table

Thickness = Higher (BFw or Water Table) − Water Table

CAL0312

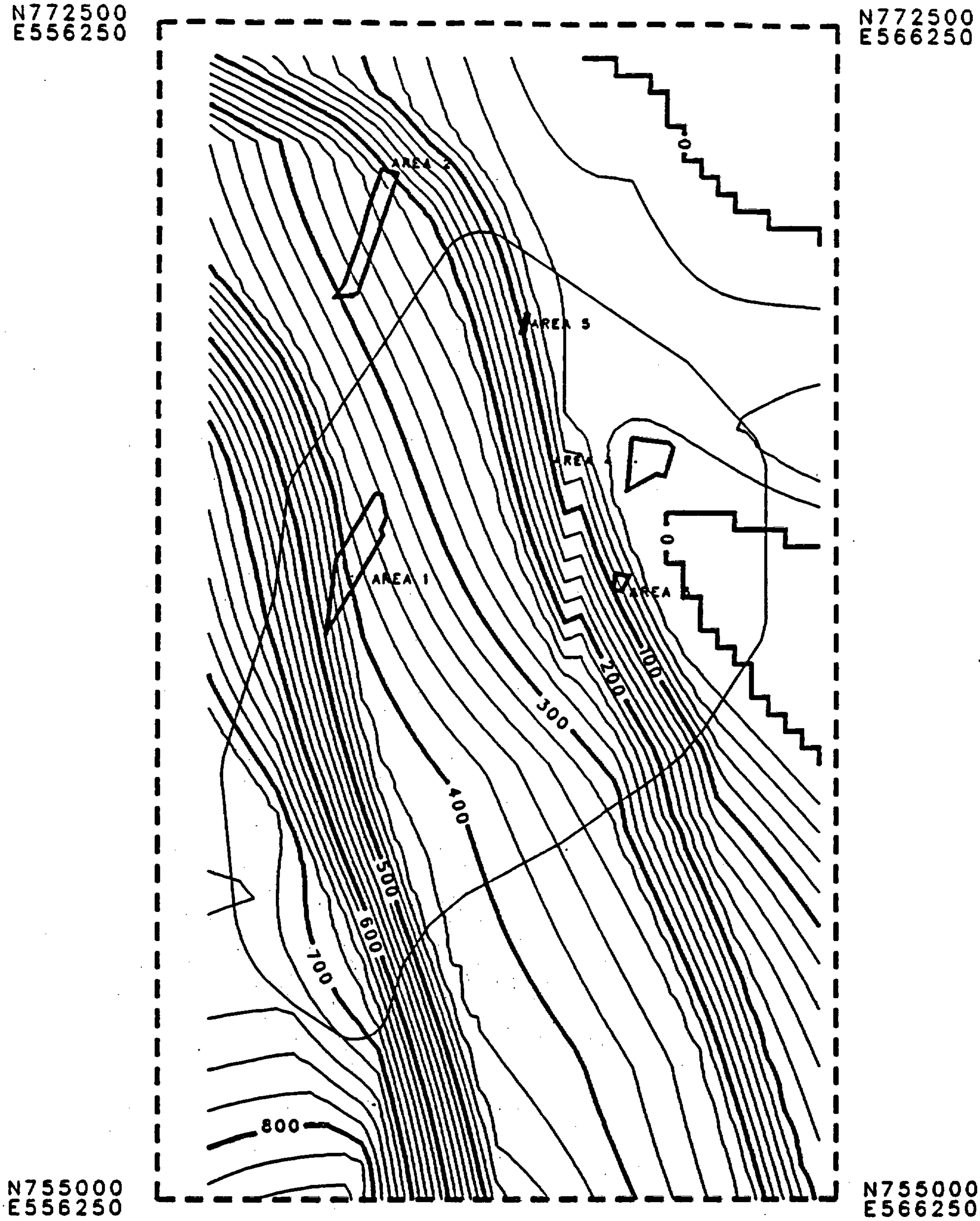


Contour interval of 20 feet

Combined Thickness of Units Tsw2 (Below the Repository), TSw3, CHnz, CFUn, CFMn, all Above the Water Table

Thickness = CAL0305 + CAL0306 + CAL0308 + CAL0310 + CAL0312

CAL0313

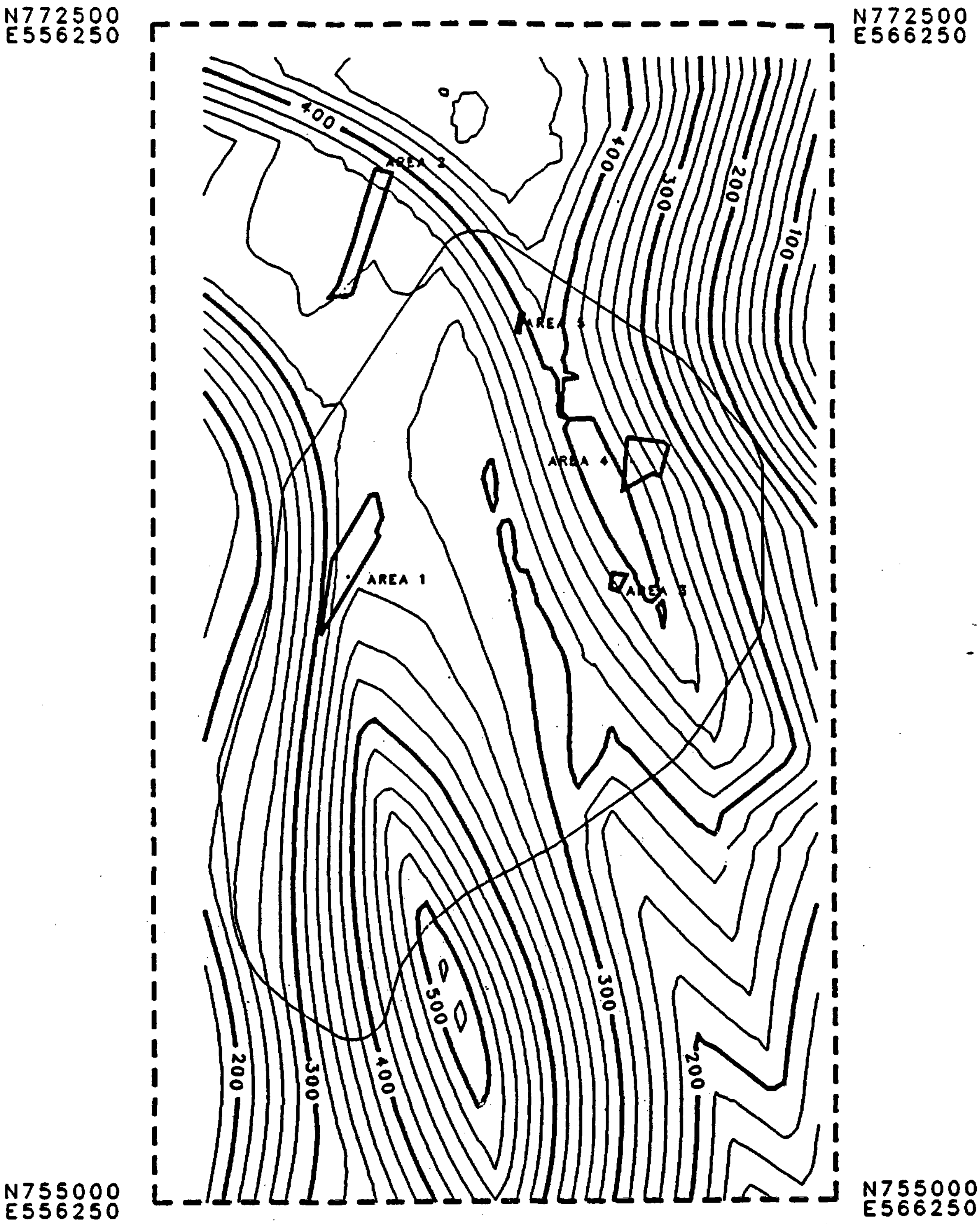


Contour interval of 20 feet

Combined Thickness of Units CHnv, PPw, and BFw Above the Water Table

Thickness = CAL0307 + CAL0309 + CAL0311

CAL0314

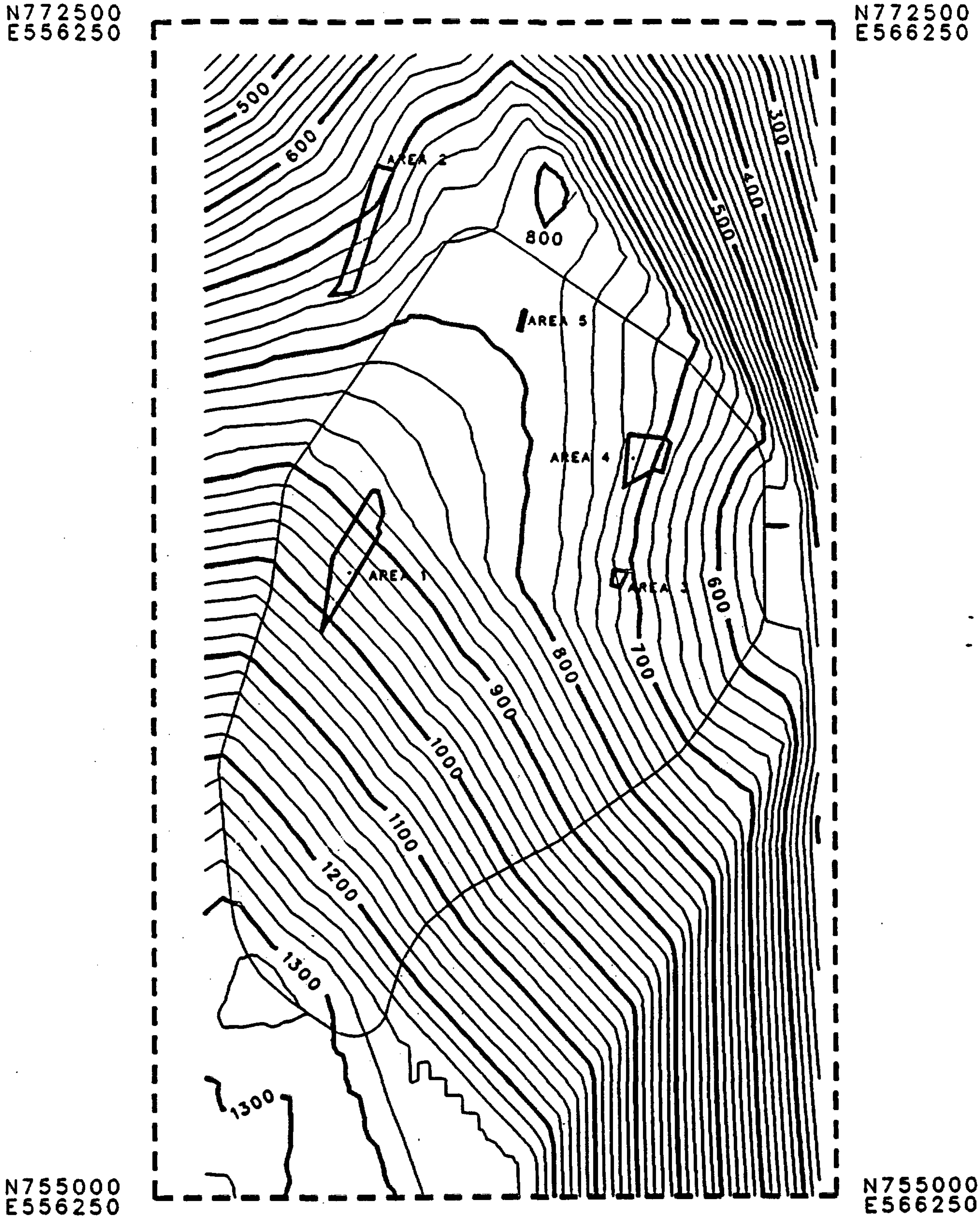


Contour interval of 20 feet

Thickness of Zeolitic Zone

CAL0315

Thickness = Unit CHnz (Below Tzz and Above Water Table)
+
Unit CFUn (Below Tzz and Above Water Table)

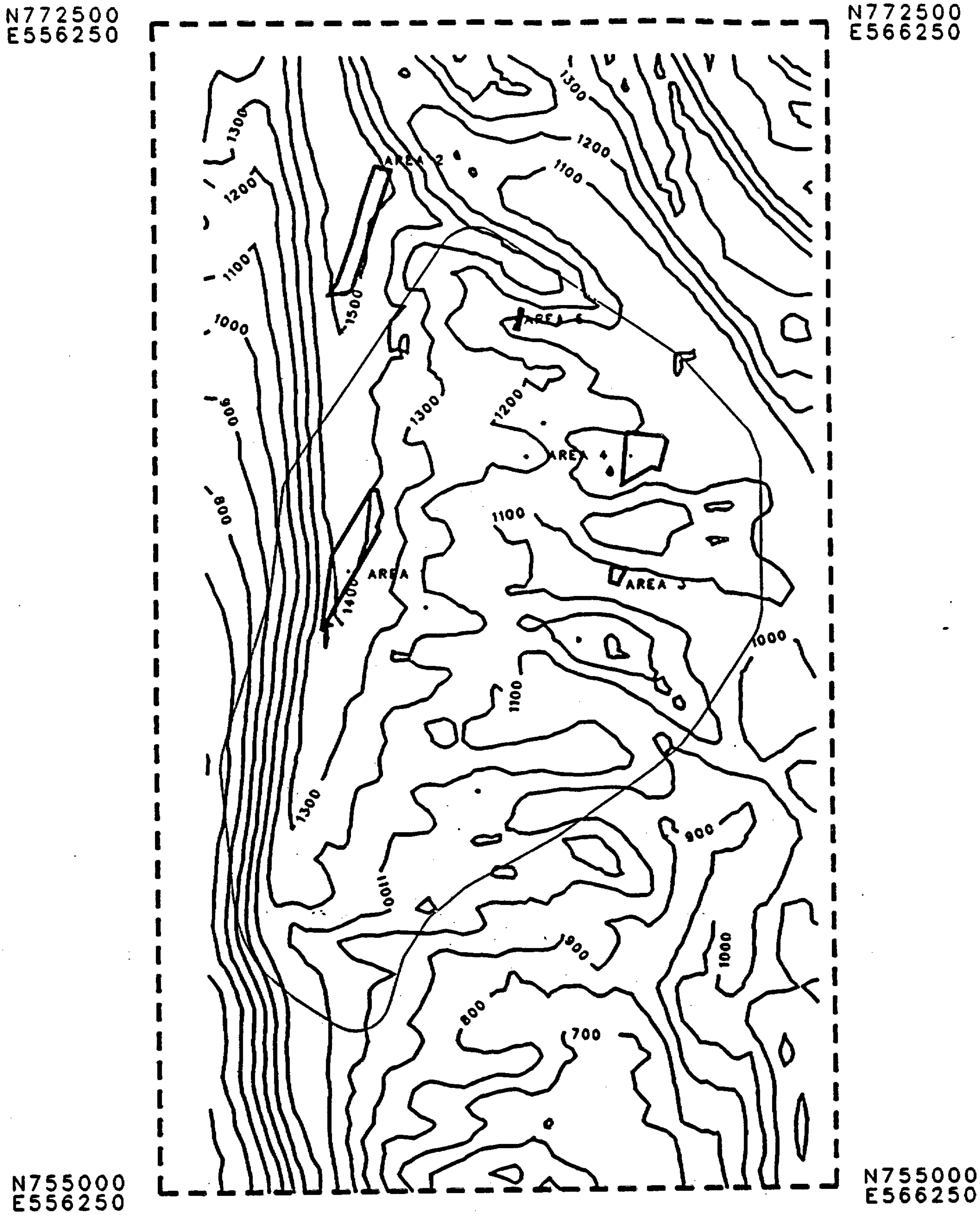


Contour interval of 20 feet

Thickness of Rocks Between the Repository Floor and the Water Table

Thickness = Repository Floor − Water Table

CAL0316

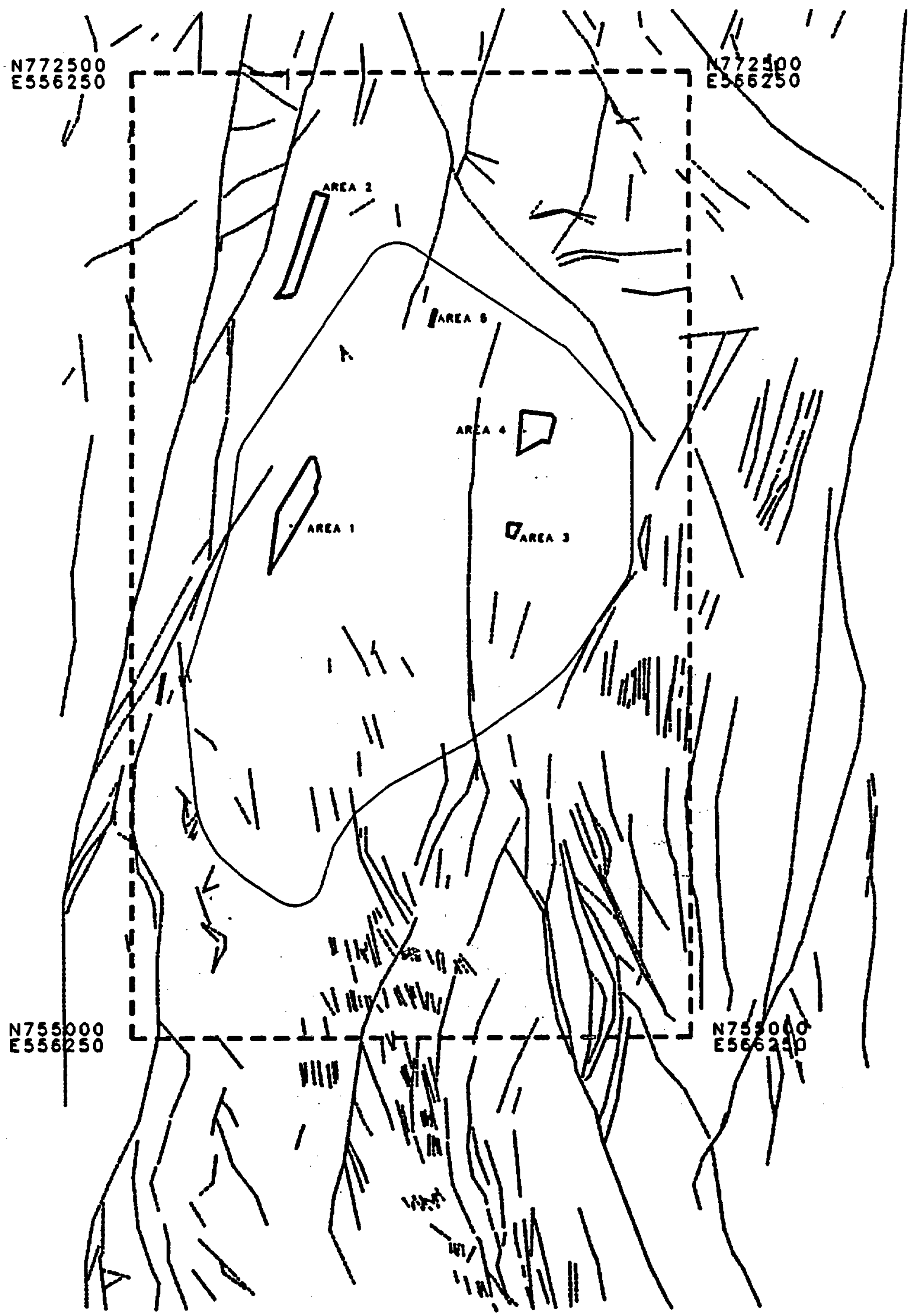


Contour interval is 100 feet

Thickness of Overburden Between the Repository Floor and Surface Topography

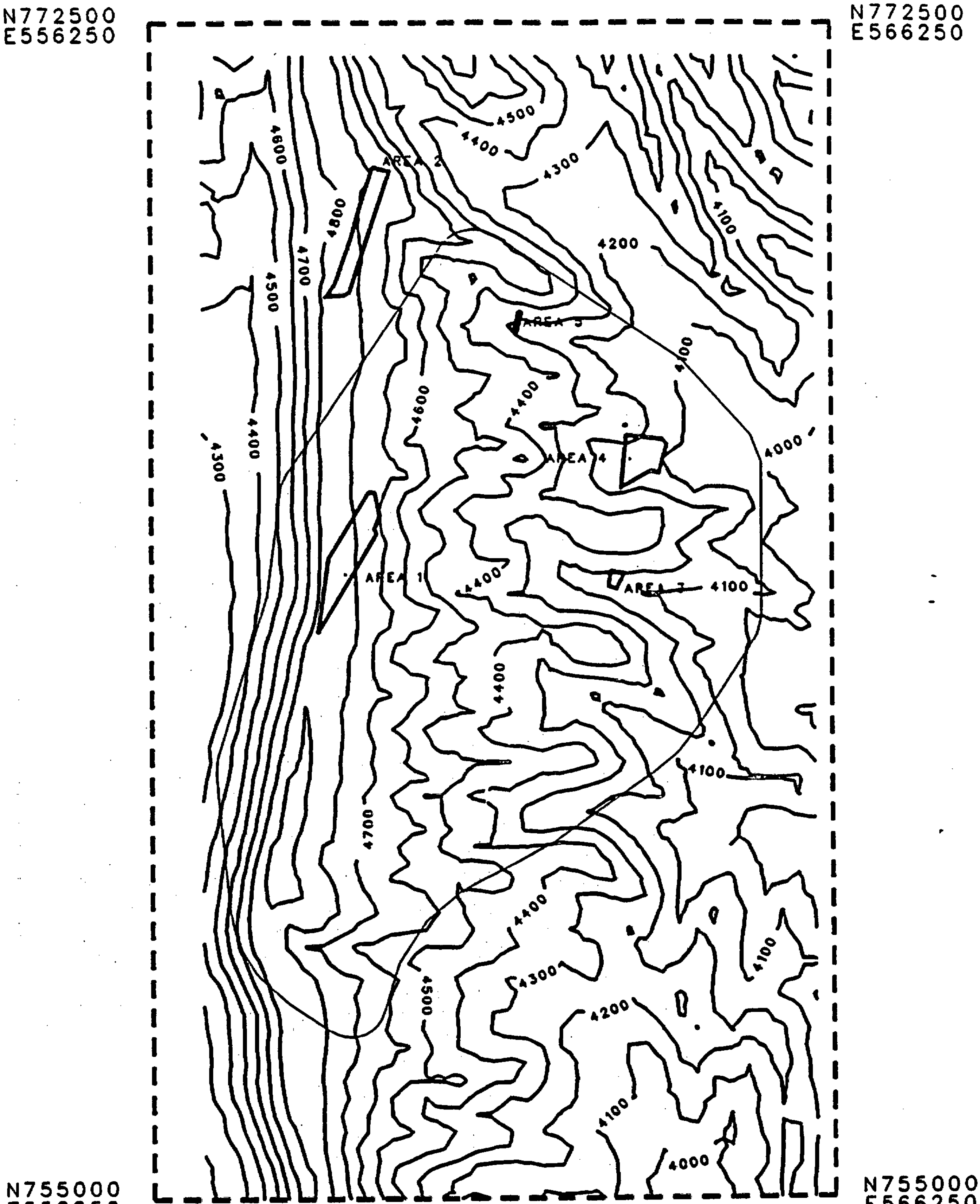
CAL0317

Thickness = Topography − Repository Floor



Surface Fault Traces in Vicinity of Yucca Mountain

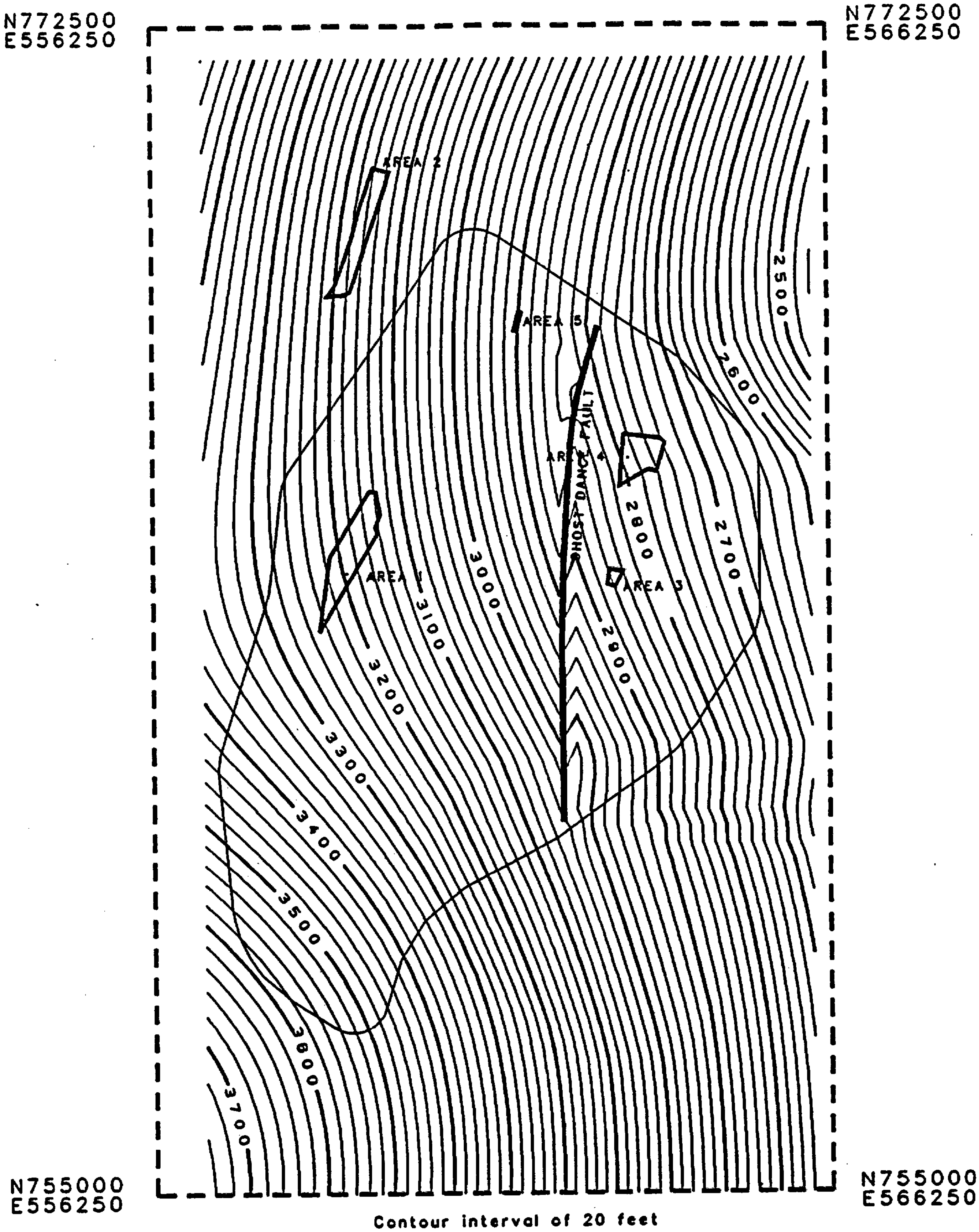
CAL0318



Contour interval is 100 feet

Surface Topography at
Yucca Mountain

CAL0319



Structure Contour Map of the Base of Unit TSw3

CAL0320

FILE: [JOB.260]CAL0321.TXT

This file contains the thickness of the five Site Points from Bertram, 1984, (SAND 84-1003, page 73), as requested.

These values were obtained from product CAL0305.

Points on the terrain model: DD:[JOB.260]REF0235.TM;2
01/17/89 09:59:48

Site Point	X (ft)	Y (ft)	Thickness (ft)
1	559100.00	764300.00	165.05
2	559600.00	770300.00	35.38
3	563100.00	764100.00	195.92
4	563300.00	766000.00	287.66
5	561653.00	768046.00	257.81

These values were obtained from product CAL0306.

Points on the terrain model: DD:[JOB.260]REF0237.TM;2
01/17/89 10:02:50

Site Point	X (ft)	Y (ft)	Thickness (ft)
1	559100.00	764300.00	55.27
2	559600.00	770300.00	72.91
3	563100.00	764100.00	61.71
4	563300.00	766000.00	45.28
5	561653.00	768046.00	50.13

These values were obtained from product CAL0307.

Points on the terrain model: DD:[JOB.260]REF0239.TM;2
01/17/89 10:05:07

Site Point	X (ft)	Y (ft)	Thickness (ft)
1	559100.00	764300.00	265.87
2	559600.00	770300.00	114.79
3	563100.00	764100.00	28.82
4	563300.00	766000.00	12.08
5	561653.00	768046.00	57.06

These values were obtained from product CAL0308.

Points on the terrain model: DD:[JOB.260]REF0240.TM;2
01/17/89 10:07:43

Site Point	X (ft)	Y (ft)	Thickness (ft)
1	559100.00	764300.00	87.81
2	559600.00	770300.00	374.65
3	563100.00	764100.00	379.54
4	563300.00	766000.00	382.12
5	561653.00	768046.00	392.35

These values were obtained from product CAL0309.

Points on the terrain model: DD:[JOB.260]REF0251.TM;3
01/17/89 10:10:42

Site Point	X (ft)	Y (ft)	Thickness (ft)
1	559100.00	764300.00	124.47
2	559600.00	770300.00	90.47
3	563100.00	764100.00	52.66
4	563300.00	766000.00	0.00
5	561653.00	768046.00	34.89

These values were obtained from product CAL0310.

Points on the terrain model: DD:[JOB.260]REF0252.TM;2
01/17/89 10:13:56

Site Point	X (ft)	Y (ft)	Thickness (ft)
1	559100.00	764300.00	244.64
2	559600.00	770300.00	0.00
3	563100.00	764100.00	0.00
4	563300.00	766000.00	0.00
5	561653.00	768046.00	0.00

These values were obtained from product CAL0311.

Points on the terrain model: DD:[JOB.260]REF0257.TM;3
01/17/89 10:17:17

Site Point	X (ft)	Y (ft)	Thickness (ft)
1	559100.00	764300.00	4.46
2	559600.00	770300.00	0.00
3	563100.00	764100.00	0.00
4	563300.00	766000.00	0.00
5	561653.00	768046.00	0.00

These values were obtained from product CAL0312.

Points on the terrain model: DD:[JOB.260]REF0242.TM;1
01/17/89 10:22:23

Site Point	X (ft)	Y (ft)	Thick- ness (ft)
1	559100.00	764300.00	0.00
2	559600.00	770300.00	0.00
3	561653.00	768046.00	0.00
4	563100.00	764100.00	0.00
5	563300.00	766000.00	0.00

These values were obtained from product CAL0313.

Points on the terrain model: DD:[JOB.260]REF0254.TM;1
01/13/89 15:03:32

Site Point	X (ft)	Y (ft)	Thick- ness (ft)
1	559100.00	764300.00	552.77
2	559600.00	770300.00	482.94
3	563100.00	764100.00	637.17
4	563300.00	766000.00	786.50
5	561653.00	768046.00	700.29

These values were obtained from product CAL0314.

Points on the terrain model: DD:[JOB.260]REF0262.TM;4
01/13/89 17:11:06

Site Point	X (ft)	Y (ft)	Thick- ness (ft)
1	559100.00	764300.00	394.81
2	559600.00	770300.00	205.27
3	563100.00	764100.00	81.48
4	563300.00	766000.00	12.08
5	561653.00	768046.00	91.96

These values were obtained from product CAL0315.

Points on the terrain model: DD:[JOB.260]REF0266.TM;2
01/17/89 13:39:33

Site Point	X (ft)	Y (ft)	Thick- ness (ft)
1	559100.00	764300.00	332.45

2	559600.00	770300.00	374.65
3	563100.00	764100.00	379.54
4	563300.00	766000.00	382.12
5	561653.00	768046.00	392.35

These values were obtained from product CAL0316.

Points on the terrain model: DD:[JOB.260]REF0229.TM;1
01/13/89 18:04:57

Site Point	X (ft)	Y (ft)	Thick-ness (ft)
1	559100.00	764300.00	947.58
2	559600.00	770300.00	688.21
3	563100.00	764100.00	718.64
4	563300.00	766000.00	727.13
5	561653.00	768046.00	792.25

These values were obtained from product CAL0317.

Points on the terrain model: DD:[JOB.260]REF0263.TM;2
01/13/89 17:47:00

Site Point	X (ft)	Y (ft)	Thick-ness (ft)
1	559100.00	764300.00	1409.86
2	559600.00	770300.00	1515.27
3	563100.00	764100.00	1054.08
4	563300.00	766000.00	1042.07
5	561653.00	768046.00	1084.11

These values were obtained from product CAL0319.

Points on the terrain model: DD:[JOB.260]REF0001.TM;2
01/17/89 12:37:43

Site Point	X (ft)	Y (ft)	Thick-ness (ft)
1	559100.00	764300.00	4826.04
2	559600.00	770300.00	4777.68
3	563100.00	764100.00	4169.72
4	563300.00	766000.00	4166.00
5	561653.00	768046.00	4292.88

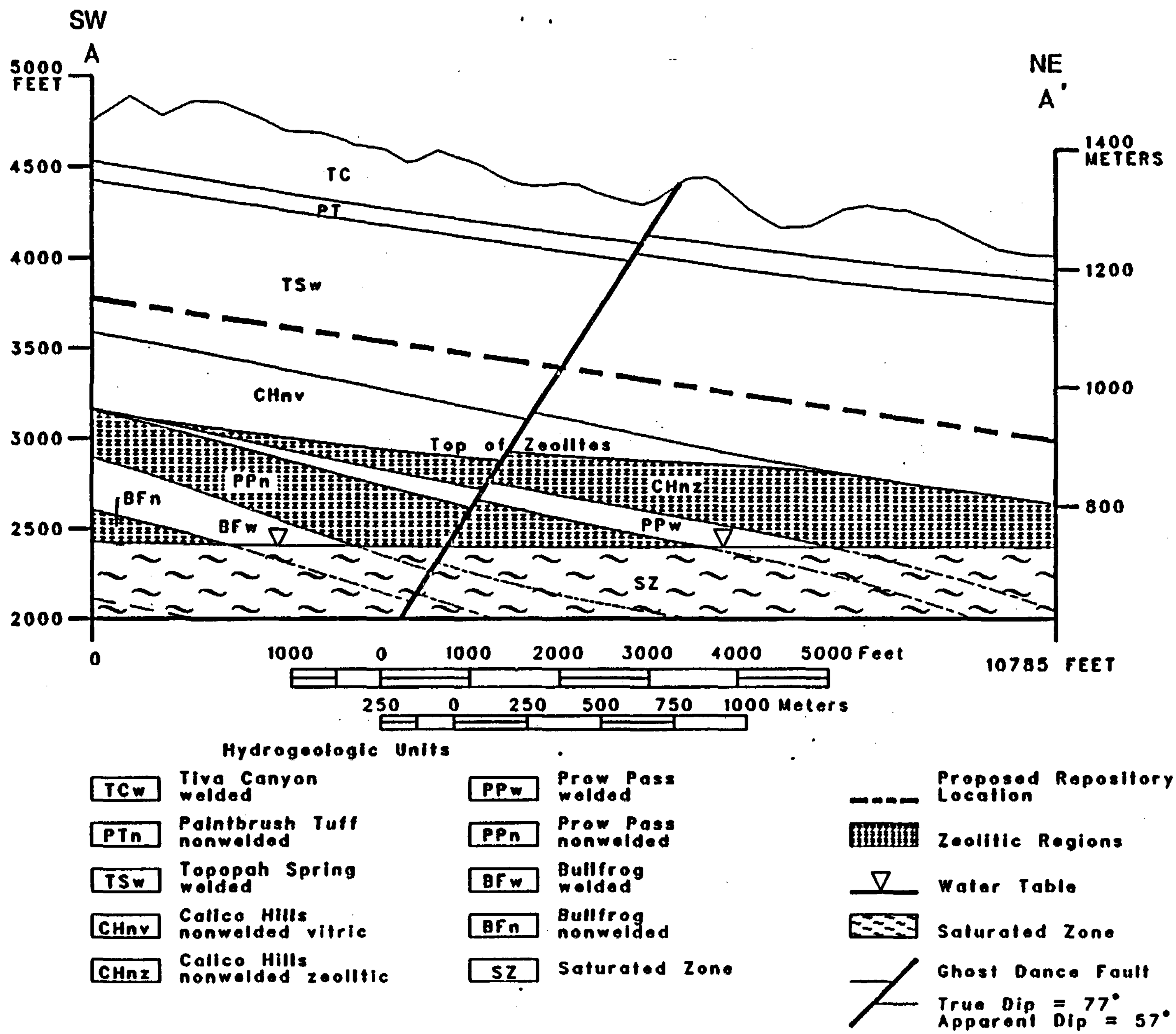
These values were obtained from product CAL0320.

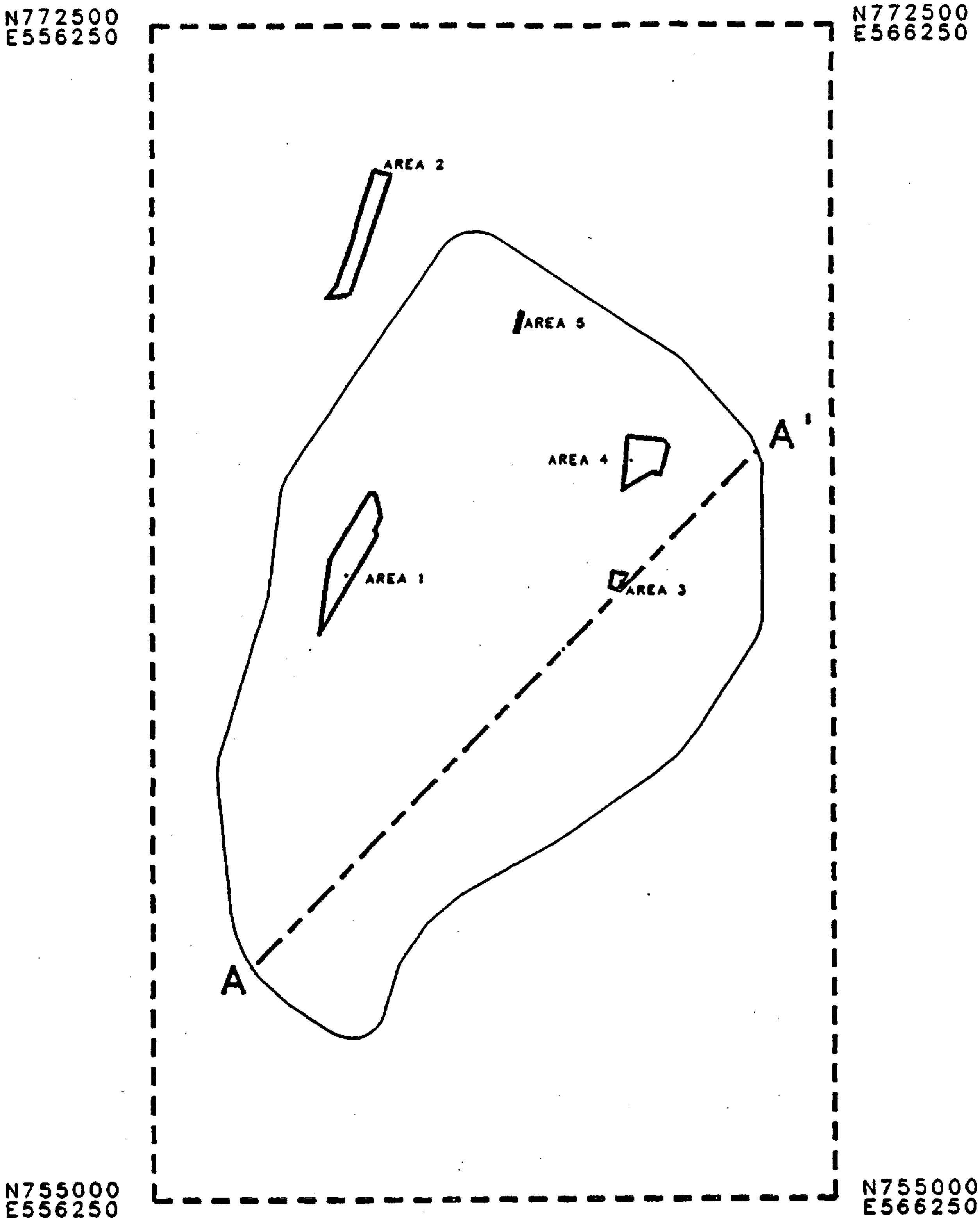
Points on the terrain model: DD:[JOB.260]REF0202.TM;3
01/17/89 12:51:36

Site	X	Y	Thick-

!Point !	(ft) !	(ft)	!ness (ft)!
1	559100.00	764300.00	3195.86
2	559600.00	770300.00	3154.12
3	563100.00	764100.00	2858.02
4	563300.00	766000.00	2791.00
5	561653.00	768046.00	2900.83

Figure sent to Scott Sinnock from David Eley, Sandia National Laboratories, Albuquerque, New Mexico by overnight mail under separate cover

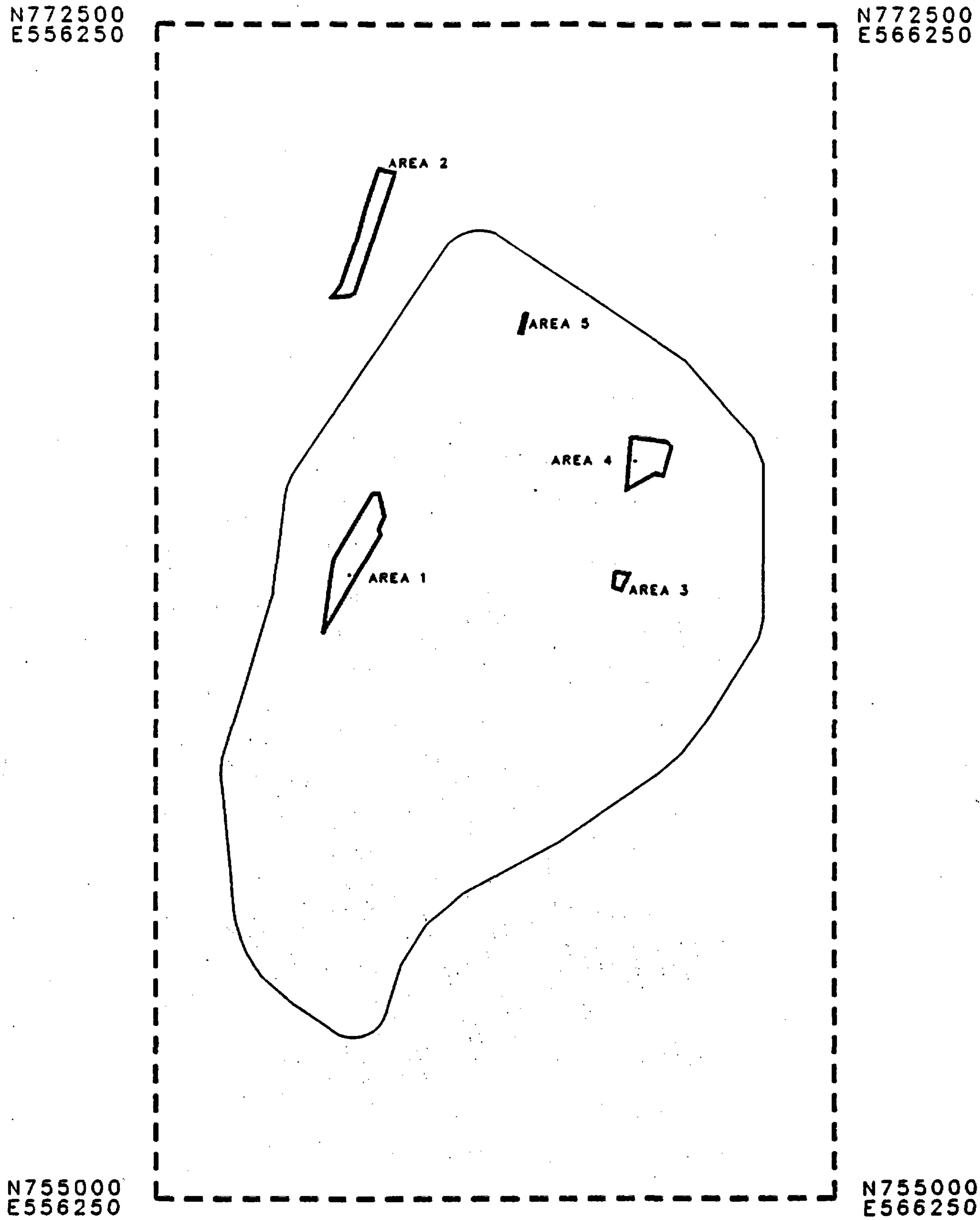

SW
A
NE
A'
5000 FEET
4500
4000
3500
3000
2500
2000
1400 METERS
1200
1000
800
TC
PT
TSw
CHnv
Top of Zeolites
CHnz
PPn
BFn
BFw
PPw
SZ
0
10785 FEET
1000 0 1000 2000 3000 4000 5000 Feet
250 0 250 500 750 1000 Meters
Hydrogeologic Units
TCw Tiva Canyon welded
PTn Paintbrush Tuff nonwelded
TSw Topopah Spring welded
CHnv Calico Hills nonwelded vitric
CHnz Calico Hills nonwelded zeolitic
PPw Prow Pass welded
PPn Prow Pass nonwelded
BFw Bullfrog welded
BFn Bullfrog nonwelded
SZ Saturated Zone
Proposed Repository Location
Zeolitic Regions
Water Table
Saturated Zone
Ghost Dance Fault
True Dip = 77°
Apparent Dip = 57°



Contour interval of 20 feet

Section A-A, with Repository Boundary and Alternative ESF Areas

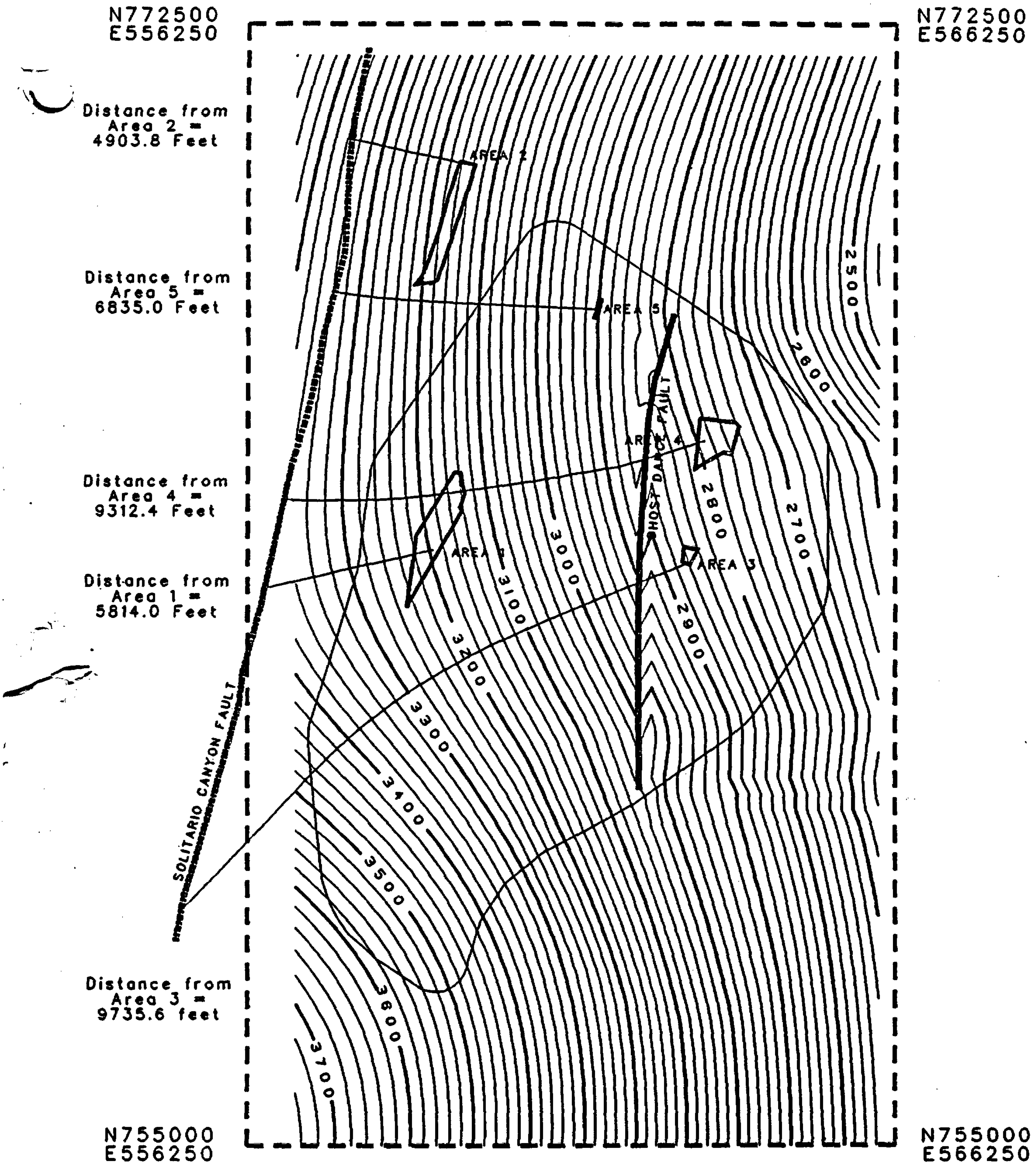
CAL0322



Contour interval of 20 feet

Repository Boundary and Alternative ESF Areas

CAL0323



Contour interval of 20 feet

Structure Contour Map of the Base of Unit TSw3 with Distances from Areas to Solitario Canyon Fault

CAL0327