DRC-2010-001422

DENISON MINES

Denison Mines (USA) Corp.
1050 17th Street, Suite 950
Denver, CO 80265
USA

Tel : 303 628-7798
Fax : 303 389-4125

www.denisonmines.com

January 20, 2010

Mr. Dane Finerfrock, Executive Secretary
Utah Radiation Control Board
Utah Department of Environmental Quality
168 North 1950 West
P.O. Box 144810
Salt Lake City, UT 84114-4810

Dear Mr. Finerfrock:

Re: <u>White Mesa Uranium Mill – First Round of Interrogatories From Review of License Amendment Request and Environmental Report for Cell 4B – *Referenced Documents*</u>

Enclosed please find one (1) CD containing the White Mesa Mill Tailings Cover Design Report, prepared by Titan Environmental, dated October 1996.

Please contact Harold Roberts at (303) 389-4160 with any questions or concerns

Yours very truly,

DENISON MINES (USA) CORP.

Meredith Goble
Records Admininstrator/Paralegal

cc: Robert D. Baird, PE – URS Corporation

Encl.

TITAN Environmental

TAILINGS COVER DESIGN
White Mesa Mill

Prepared For:

Energy Fuels Nuclear, Inc.
1515 Arapahoe, Suite 900
Denver, CO 80202

October 1996

By:

TITAN Environmental Corporation
7939 East Arapahoe Road, Suite 230
Englewood, Colorado 80112

TABLE OF CONTENTS

LIST OF FIGURES

LIST APPENDICES

The following sections describe design considerations, complete with calculations performed and parameters utilized, in developing the tailings impoundment soil cover to meet regulatory requirements.

1.1 Radon Flux Attenuation

The Environmental Protection Agency (EPA) rules in 40 Code of Federal Regulation (CFR) Part 192 require that a "uranium tailings cover be designed to produce reasonable assurance that the radon-222 release rate would not exceed 20 pCi/m^2/sec for a period of 1,000 years to the extent reasonably achievable and in any case for at least 200 years when averaged over the disposal area over at least a one year period" (NRC, 1989). NRC regulations presented in 10 CFR Part 40 also restrict radon flux to less than 20 pCi/m^2/sec. The following sections present the analyses and design for a soil cover which meets this requirement.

1.1.1 Predictive Analysis

The soil cover for the tailings cells at White Mesa Mill was evaluated for attenuation of radon gas using the digital computer program, RADON, presented in the NRC's Regulatory Guide 3.64 (Task WM 503-4) entitled "Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers". The RADON model calculates radon-222 flux attenuation by multi-layered earthen uranium mill tailings covers, and determines the minimum cover thickness required to meet NRC and EPA standards. The RADON model uses the following soil properties in the calculation process:

- Soil layer thickness [centimeters (cm)];
- Soil porosity (percent);
- Density [grams-per-cubic centimeter (gm/cm^3)];
- Weight percent moisture (percent);
- Radium activity (piC/g);
- Radon emanation coefficient (unitless); and

- Diffusion coefficient [square centimeters-per-second (cm^2/sec)].

Physical and radiological properties for tailings and random fill were analyzed by Chen and Associates (1987) and Rogers and Associates (1988). Clay physical data from Section 16 was analyzed by Advanced Terra Testing (1996) and Rogers and Associates (1996). See Appendix A for laboratory test data results.

The RADON model was performed for the following cover section (from top to bottom):

- two feet compacted random fill;
- one foot compacted clay; and
- a minimum of three feet random fill occupying the freeboard space between the tailings and clay layer.

The three layers are compacted to 95 percent maximum dry density. The top riprap layer was not included as part of the soil cover for the radon attenuation calculation.

The results of the RADON modeling exercise show that the uranium tailings cover configuration will attenuate radon flux emanating from the tailings to a level of 17.6 pCi/m^2/sec. This number was conservatively calculated as it takes into account the freeze/thaw effect on the uppermost part (6.8 inches) of the cover (Section 1.3). The soil cover and tailing parameters used to run the RADON model, in addition to the RADON input and output data files, are presented in Appendix B as part of the Radon Calculation brief. Based on the model results, the soil cover design of six-foot thickness will meet the requirements of 40 CFR Part 192 and 10 CFR Part 40.

1.1.2 Empirical Data

Radon gas flux measurements have been made at the White Mesa Mill tailings piles over Cells 2 and 3 (see Appendix C). These cells are currently covered with three to four feet of random fill. Radon flux measurements, averaged over the covered areas, were as follows (EFN, 1996):

	1994	1995
Cell 2	7.7 pCi/m^2/sec	6.1 pCi/m^2/sec
Cell 3	7.5 pCi/m^2/sec	11.1 pCi/m^2/sec

Empirical data suggest that the random fill cover, alone, is currently providing an effective barrier to Radon flux. Thus, the proposed tailings cover configuration, which is thicker, moisture adjusted, contains a clay layer and is compacted, is expected to attenuate the Radon flux to a level below that predicted by the RADON model. The field radon flux measurements confirm the conservatism of the cover design. This conservatism is necessary, however, to guarantee compliance with NRC regulations under long term climatic conditions over the required design life of 200 to 1,000 years.

1.2 Infiltration Analysis

The tailings ponds at White Mesa Mill are lined with synthetic geomembrane liners which under certain climatic conditions, could potentially lead to the long-term accumulation of water from infiltration of precipitation. Therefore, the soil cover was evaluated to estimate the potential magnitude of infiltration into the capped tailings ponds. The Hydrologic Evaluation of Landfill Performance (HELP) model, Version 3.0 (EPA, 1994) was used for the analysis. HELP is a quasi two-dimensional hydrologic model of water movement across, into, through, and out of capped and lined impoundments. The model utilizes weather, soil, and engineering design data as input to the model, to account for the effects of surface storage, snowmelt, run-off, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, and unsaturated vertical drainage on the specific design, at the specified location.

The soil cover was evaluated based on a two-foot compacted random fill layer over a one-foot thick, compacted clay layer. The soil cover layers were modeled based on material placement at a minimum of 95 percent of the maximum dry density, and within two percent of the optimum moisture content per American society for Testing and Materials (ASTM) requirements. The top riprap layer and the bottom random fill layer were not included as part of the soil cover for infiltration calculations. These two layers are not playing any role in controlling the infiltration through the cover material.

The random fill will consist of clayey sands and silts with random amounts of gravel and rock-size materials. The average hydraulic conductivity of several samples of random fill was calculated, based on laboratory tests, to be 8.87×10^{-7} cm/sec. The hydraulic conductivity of the clay source from Section 16 was measured in the laboratory to be 3.7×10^{-8} cm/sec. Geotechnical soil properties and laboratory data are presented in Appendix A.

Key HELP model input parameters include:

- Blanding, Utah, monthly temperature and precipitation data, and HELP model default solar radiation, and evapotranspiration data from Grand Junction, Colorado. Grand Junction is located north east of Blanding in similar climate and elevation;

- Soil cover configuration identifying the number of layers, layer types, layer thickness, and the total covered surface area;

- Individual layer material characteristics identifying saturated hydraulic conductivity, porosity, wilting point, field capacity, and percent moisture; and

- Soil Conservation Service runoff curve numbers, evaporative zone depth, maximum leaf area index, and anticipated vegetation quality.

Water balance results, as calculated by the HELP model, indicate that precipitation would either run-off the soil cover or be evaporated. Thus, model simulations predict zero infiltration of surface water through the soil cover, as designed. These model results are conservative and take into account the freeze/thaw effects on the uppermost part (6.8 inches) of the cover (Section 1.3). The HELP model input and output for the tailings soil cover are presented in the HELP Model calculation brief included as Appendix D.

1.3 Freeze/Thaw Evaluation

The tailings soil cover of one foot of compacted clay covered by two feet of random fill was evaluated for freeze/thaw impacts. Repeated freeze/thaw cycles have been shown to increase the bulk soil permeability by breaking down the compacted soil structure.

The soil cover was evaluated for freeze/thaw effects using the modified Berggren equation as presented in Aitken and Berg (1968) and recommended by the NRC (U.S. Department of Energy, 1988). This evaluation was based on the properties of the random fill and clay soil, and meteorological data from both Blanding, Utah and Grand Junction, Colorado.

The results of the freeze/thaw evaluation indicate that the anticipated maximum depth of frost penetration on the soil cover would be less than 6.8 inches. Since the random fill layer is two feet thick, the frost depth would be confined to this layer and would not penetrate into the underlying clay layer. The performance of the soil cover to attenuate radon gas flux below the prescribed standards, and prevent surface water infiltration, would not be compromised. The input data and results of the freeze/thaw evaluation are presented in the Effects of Freezing on Tailings Covers Calculation brief included as Appendix E.

1.4 Soil Cover Erosion Protection

A riprap layer was designed for erosion protection of the tailings soil cover. According to NRC guidance, the design must be adequate to protect the soil/tailings against exposure and erosion for 200 to 1,000 years (NRC, 1990). Currently, there is no standard industry practice for stabilizing tailings for 1,000 years. However, by treating the embankment slopes as wide channels, the hydraulic design principles and practices associated with channel design were used to design stable slopes that will not erode. Thus, a conservative design based on NRC guidelines was developed. Engineering details and calculations are summarized in the Erosion Protection Calculation brief provided in Appendix F.

Riprap cover specifications for the top and side slopes were determined separately as the side slopes are much steeper than the slope of the top of the cover. The size and thickness of the riprap on the top of the cover was calculated using the Safety Factor Method (NUREG/CR-4651, 1987), while the Stephenson Method (NUREG/CR-4651, 1987) was used for the side slopes. These methodologies were chosen based on NRC recommendations (1990).

By the Safety Factor Method, riprap dimensions for the top slope were calculated in order to achieve a slope "safety factor" of 1.1. For the top of the soil cover, with a slope of 0.2 percent, the Safety Factor Method indicated a median diameter (D_{50}) riprap of 0.28 inches is required to stabilize the top slope. However, this dimension must be modified based on the long-term durability of the specific rock type to be used in construction. The suitability of rock to be used as a protective cover must be assessed by laboratory tests to determine the physical characteristics of the rocks. The sandstones from the confluence of Westwater and Cottonwood Canyons require an oversizing factor of 25 percent. Therefore, riprap created from this sandstone source should have a D_{50} size of at least 0.34 inches and should have an overall layer thickness of at least three inches on the top of the cover.

Riprap dimensions for the side slopes were calculated using Stephenson Method equations. The side slopes of the cover are designed at 5H:1V. At this slope, Stephenson's Method indicated the unmodified riprap D_{50} of 3.24 inches is required. Again assuming that the on-site sandstone will be used, the modified D_{50} size of the riprap should be at least 4.05 inches with an overall layer thickness of at least 12 inches.

The potential of erosion damage due to overland flow, sheetflow, and channel scouring on the top and side slopes of the cover, including the riprap layer, has been evaluated. Overland flow calculations were performed using site meteorological data, cap design specifications, and guidelines set by the NRC (NUREG/CR-4620, 1986). These calculations are included in Appendix F. According to the guidelines, overland flow velocity estimates are to be compared to "permissible velocities", which have been suggested by the NRC, to determine the potential for erosion damage. When calculated, overland flow velocity estimates exceed permissible velocities, additional cover protection should be considered. The permissible velocity for the tailings cover (including the riprap layer) is 5.0 to 6.0 feet-per-second (ft./sec.) (NUREG/CR 4620). The overland flow velocity calculated for the top of the cover is less than 2.0 ft/sec., and the calculated velocity on the side slopes is 4.9 ft/sec. Therefore, the erosion potential of the slopes, due to overland flow/channel scouring, is within acceptable limits and no additional erosion protection is required.

1.5 Slope Stability Analysis

Static and pseudostatic analyses were performed to establish the stability of the side slopes of the tailings soil cover. The side slopes are designed at an angle of 5H:1V. Because the side slope along the southern section of Cell 4A is the longest and the ground elevation drops rapidly at its base, this slope was determined to be critical and is thus the focus of the stability analyses.

The computer software package GSLOPE, developed by MITRE Software Corporation, has been used for these analyses to determine the potential for slope failure. GSLOPE applies Bishop's Method of slices to identify the critical failure surface and calculate a factor of safety (FOS). The slope geometry and properties of the construction materials and bedrock are input into the model. These data and drawings are included in the Stability Analysis of Side Slopes Calculation brief included as Appendix G. For this analysis, competent bedrock is designated at 10 feet below the lowest point of the foundation [i.e., at a 5,540-foot elevation above mean sea level (msl)]. This is a conservative estimate, based on the borehole logs supplied by Chen and Associates (1979), which indicate bedrock near the surface.

1.5.1 Static Analysis

For the static analysis, a FOS of 1.5 or more was used to indicate an acceptable level of stability. The calculated FOS is 2.91, which indicates that the slope should be stable under static conditions. Results of the computer model simulations are included in Appendix G.

1.5.2 Pseudostatic Analysis (Seismicity)

The slope stability analysis described above was repeated under pseudostatic conditions in order to estimate a FOS for the slope when a horizontal ground acceleration of 0.10g is applied. The slope geometry and material properties used in this analysis are identical to those used in the stability analysis. A FOS of 1.0 or more was used to indicate an acceptable level of stability under pseudostatic conditions. The calculated FOS is 1.903, which indicates that the slope should be stable under dynamic conditions. Details of the analysis and the simulation results are included in Appendix G.

Recently, Lawrence Livermore National Laboratory (LLNL) published a report on seismic activity in southern Utah, in which a horizontal ground acceleration of 0.12g was proposed for the White Mesa site. The evaluations made by LLNL were conservative to account for tectonically active regions that exist, for example, near Moab, Utah. Although, the LLNL report states that "...[Blanding] is located in a region known for its scarcity of recorded seismic events," the stability of the cap design slopes using the LLNL factor was evaluated. The results of a sensitivity analysis reveal that when considering a horizontal ground acceleration of 0.12g, the calculated FOS is 1.778 which is still above the required value of 1.0, indicating adequate safety under pseudostatic conditions. This analysis is also included in Appendix G.

1.6 Cover Material/Cover Material Volumes

Construction materials for reclamation will be obtained from on-site locations. Fill material will be available from the stockpiles that were generated from excavation of the cells for the tailings facility. If required, additional materials are available locally to the west of the site. A clay material source, identified in Section 16 at the southern end of the White Mesa Mill site, will be used to construct the one-foot compacted clay layer. Riprap material will be taken from on-site sandstone, located at the confluence of Westwater and Cottonwood Canyons.

Material quantities have been calculated for each of the components of the reclamation cover. Volume estimates were made for the two soil cover design options, as follows:

- Option 1: an integrated soil cover which incorporates Disposal Cells 2, 3, and 4A, and
- Option 2: a cover which includes Cells 2 and 3, where Cell 4A tailings have been excavated and placed in Cell 3.

The quantity of random fill required to bring the pond elevation up to the soil cover subgrade and construct the final slope was not calculated. This layer will be a minimum of three feet in depth and is dependent on the final tailings grade, which is not known.

For Design Option 1, construction will require the following approximate quantities of materials:

Material	Volume (cubic yards)
Clay	365,082
Random Fill	737,717
Riprap (top of cover)	82,762
Riprap (side slopes)	41,588

For Design Option 2, construction will require the following approximate quantities of materials:

Material	Volume (cubic yards)
Clay	289,514
Random Fill	585,334
Riprap (top of cover)	64,984
Riprap (side slopes)	35,885

Material quantities calculations are provided in Appendix H as part of the Tailings Cover Material Volume Calculation brief.

Figures

LEGEND

5582.6	EXISTING SPOT ELEVATION
5603.5	ELEVATION OF TOP OF COVER
—5560—	EXISTING GROUND CONTOUR

NOTES

1. THE COVER WILL MEET THE GROUND WITH A DOWNWARD SIDE SLOPE OF 5H:1V.
2. ELEVATION OF THE BERMS SHALL BE ADJUSTED TO MATCH WITH THOSE OF THE COVER.
3. CELL #1 WILL BE REMOVED DURING RECLAMATION.
4. TOPOGRAPHY BY KLH ENGINEERING FROM AERIAL PHOTOGRAPHY DATED AUGUST 23, 1993. CONTOUR INTERVAL IS 2 FT.
5. SEE FIGURES 3 AND 4 FOR CROSS SECTIONS AND DETAILS.
6. EXISTING GROUND SURFACES SHALL BE REGRADED TO CONSTRUCT THE COVER WITH A FINAL SURFACE THAT IS CONSISTENT WITH THE RECLAMATION COVER GRADING PLAN.

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	8-12-96	ISSUED FOR RECLAMATION PLAN	K.G.	[signature]	[signature]

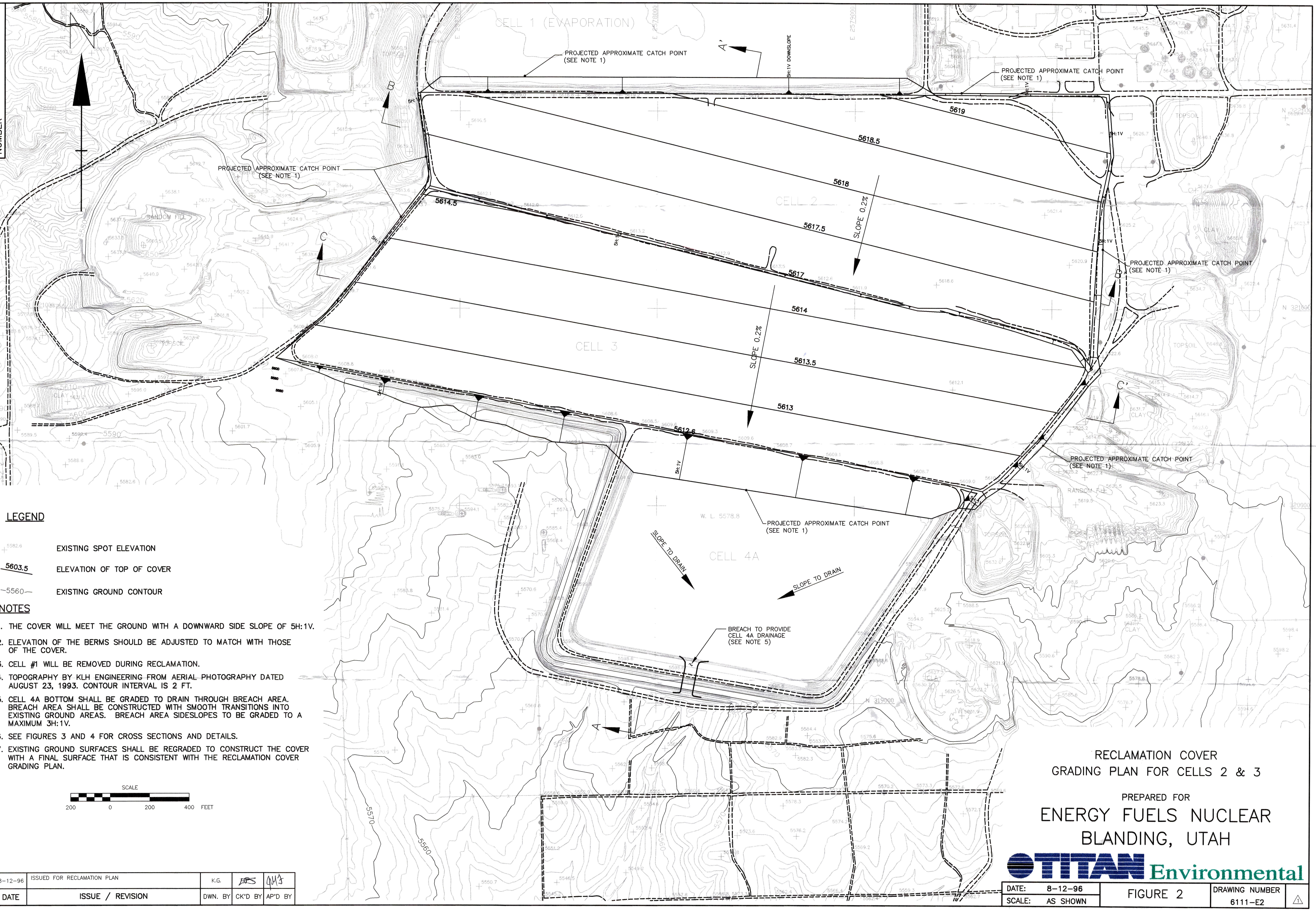
RECLAMATION COVER
GRADING PLAN FOR CELLS 2, 3 & 4A

PREPARED FOR
ENERGY FUELS NUCLEAR
BLANDING, UTAH

TITAN Environmental

DATE: 8-12-96	FIGURE 1	DRAWING NUMBER 6111-E1	1
SCALE: AS SHOWN			

DRAWING NUMBER 6111-E1



LEGEND

+5582.6	EXISTING SPOT ELEVATION
5603.5	ELEVATION OF TOP OF COVER
~5560~	EXISTING GROUND CONTOUR

NOTES

1. THE COVER WILL MEET THE GROUND WITH A DOWNWARD SIDE SLOPE OF 5H:1V.
2. ELEVATION OF THE BERMS SHOULD BE ADJUSTED TO MATCH WITH THOSE OF THE COVER.
3. CELL #1 WILL BE REMOVED DURING RECLAMATION.
4. TOPOGRAPHY BY KLH ENGINEERING FROM AERIAL PHOTOGRAPHY DATED AUGUST 23, 1993. CONTOUR INTERVAL IS 2 FT.
5. CELL 4A BOTTOM SHALL BE GRADED TO DRAIN THROUGH BREACH AREA. BREACH AREA SHALL BE CONSTRUCTED WITH SMOOTH TRANSITIONS INTO EXISTING GROUND AREAS. BREACH AREA SIDESLOPES TO BE GRADED TO A MAXIMUM 3H:1V.
6. SEE FIGURES 3 AND 4 FOR CROSS SECTIONS AND DETAILS.
7. EXISTING GROUND SURFACES SHALL BE REGRADED TO CONSTRUCT THE COVER WITH A FINAL SURFACE THAT IS CONSISTENT WITH THE RECLAMATION COVER GRADING PLAN.

SCALE
200 0 200 400 FEET

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	8-12-96	ISSUED FOR RECLAMATION PLAN	K.G.	[illegible]	[illegible]

RECLAMATION COVER
GRADING PLAN FOR CELLS 2 & 3

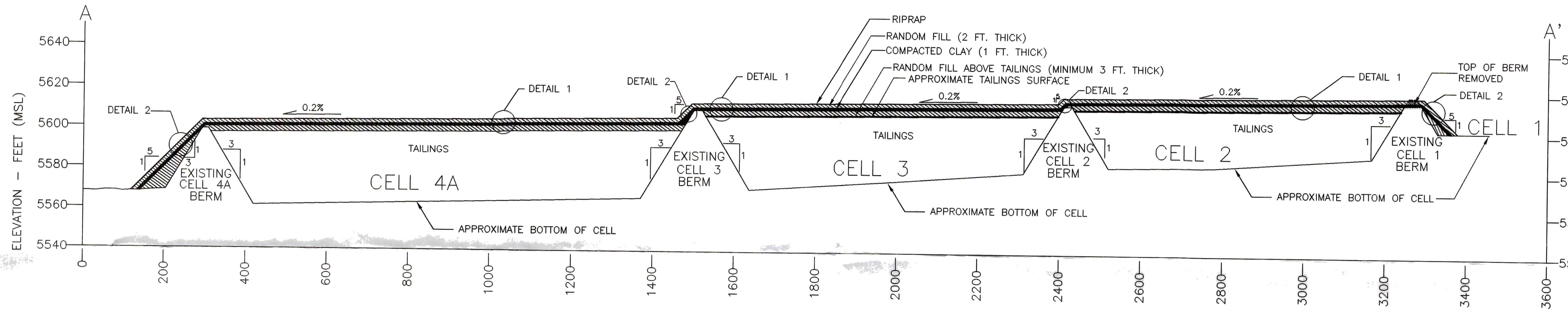
PREPARED FOR
ENERGY FUELS NUCLEAR
BLANDING, UTAH

TITAN Environmental

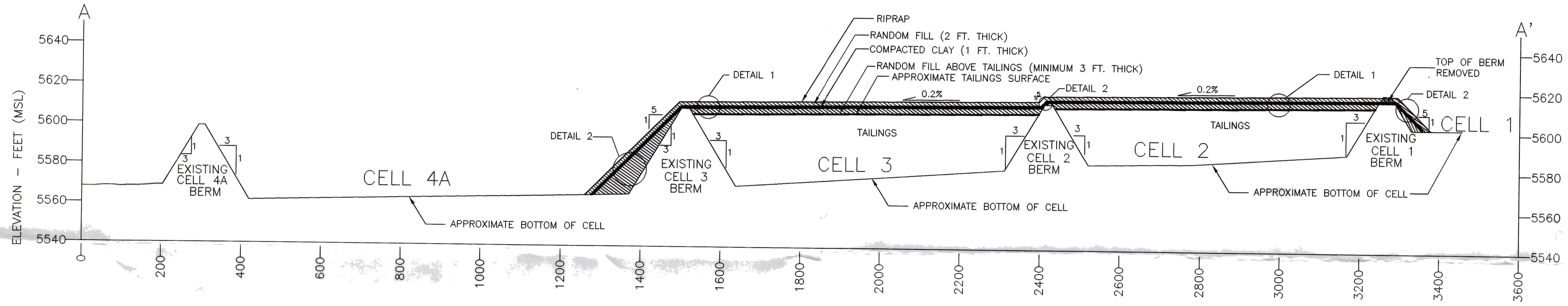
DATE: 8-12-96	SCALE: AS SHOWN	FIGURE 2	DRAWING NUMBER 6111-E2

DRAWING NUMBER 6111-E2

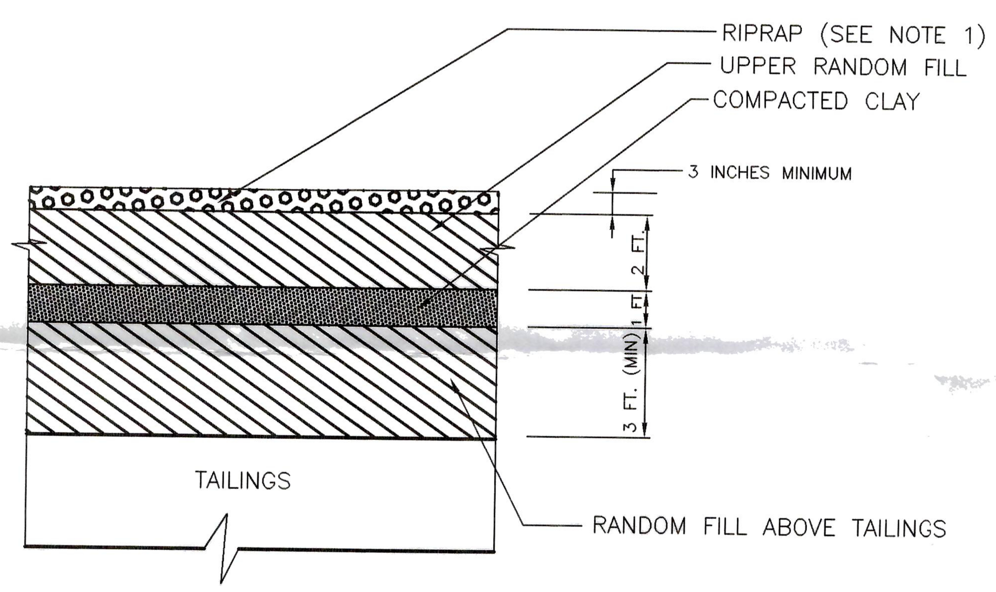
DRAWING NUMBER 6111-E3



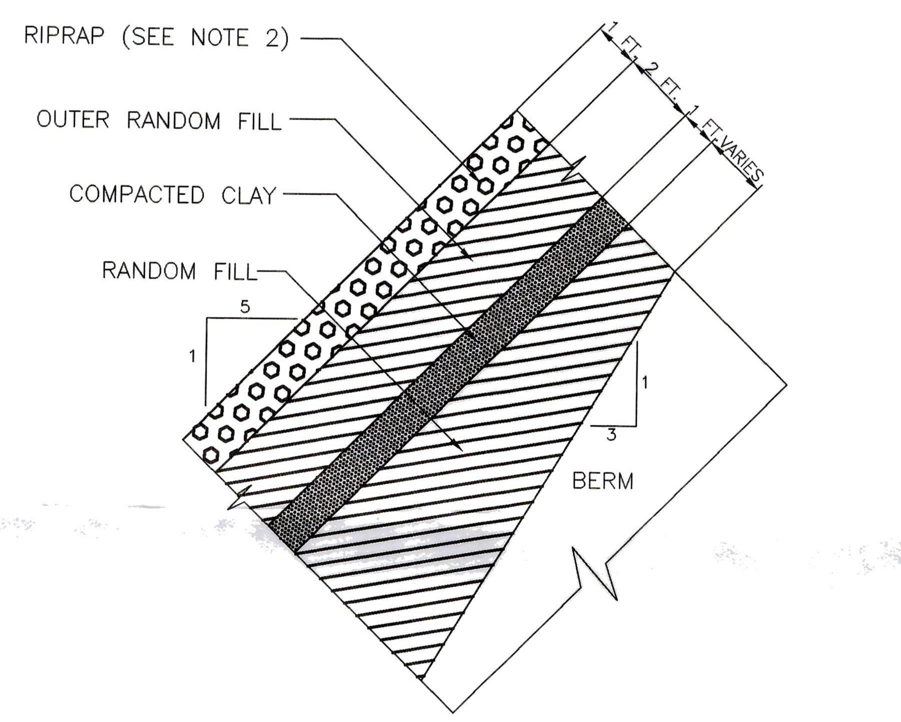
SECTION A–A' (WITH COVER ON CELLS 2, 3 & 4A)



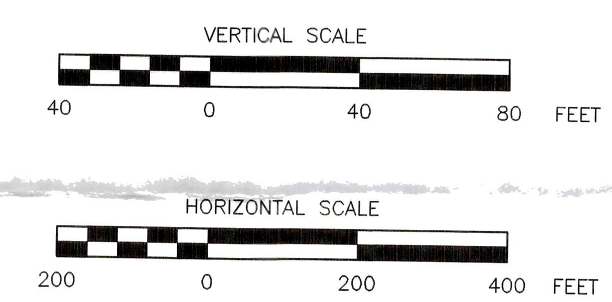
SECTION A–A' (WITH COVER ON CELLS 2 & 3)



DETAIL 1: COVER DETAIL FOR POND SURFACE AREAS
(NOT TO SCALE)



DETAIL 2: COVER DETAIL FOR SIDE SLOPES
(NOT TO SCALE)



NOTES:

1. RIPRAP PLACED ON THE TOP OF COVER WILL CONSIST OF ROCK WITH D50 MINIMUM OF 0.34 INCHES.
2. RIPRAP PLACED ON THE SIDE SLOPES OF COVER WILL CONSIST OF ROCK WITH D50 MINIMUM OF 4.1 INCHES.
3. POND BOTTOM ELEVATIONS INFERRED FROM 'CELL 4 PHASE A AND PHASE B PLAN', WESTERN ENGINEERS INC., (JANUARY 17, 1989).
4. SEE FIGURES 1 AND 2 FOR CROSS SECTION LOCATIONS
5. EXISTING GROUND SURFACES SHALL BE REGRADED TO CONSTRUCT THE COVER WITH A FINAL SURFACE THAT IS CONSISTENT WITH THE RECLAMATION COVER GRADING PLAN.

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	8-12-96	ISSUED FOR RECLAMATION PLAN	K.G.	LPB	GMJ

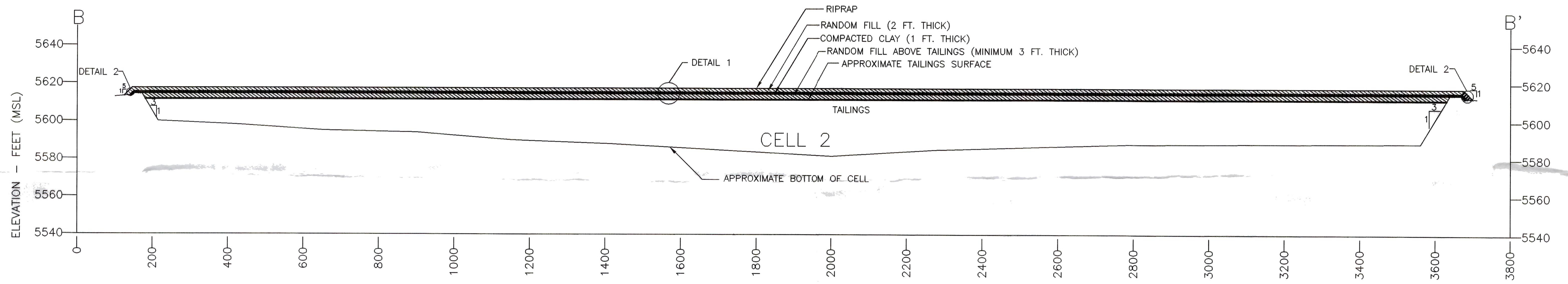
RECLAMATION COVER
CROSS SECTIONS & DETAILS
PREPARED FOR

ENERGY FUELS NUCLEAR
BLANDING, UTAH

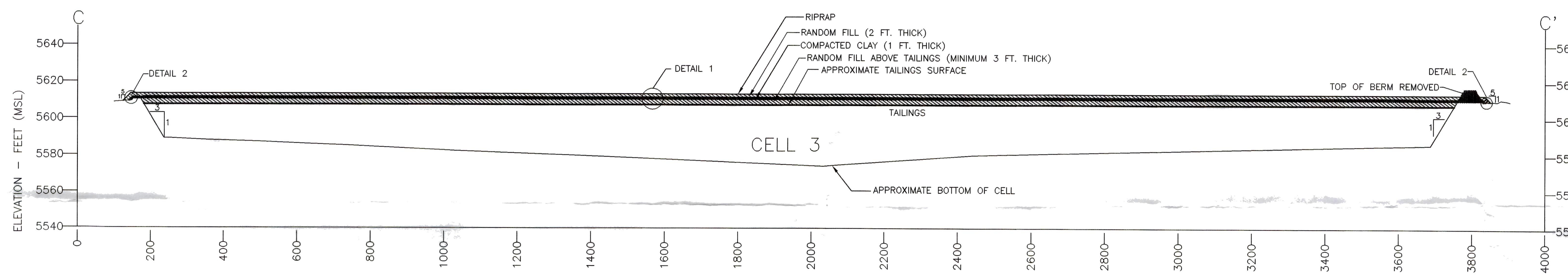
TITAN Environmental

DATE:	8-12-96	FIGURE 3	DRAWING NUMBER 6111-E3
SCALE:	AS SHOWN		

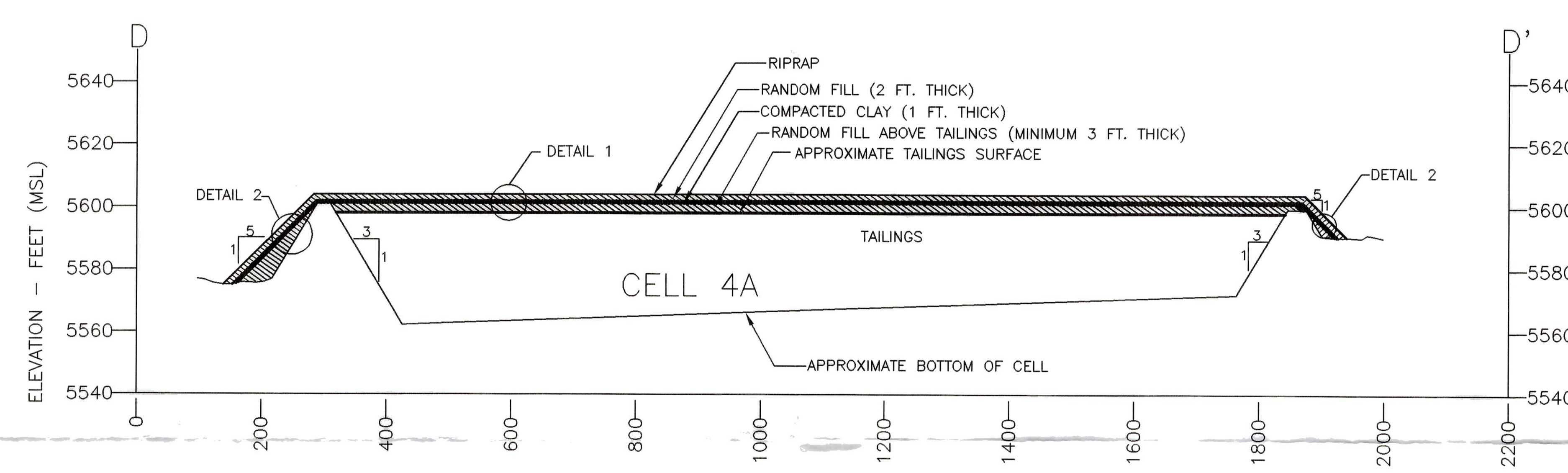
DRAWING NUMBER 6111-E4



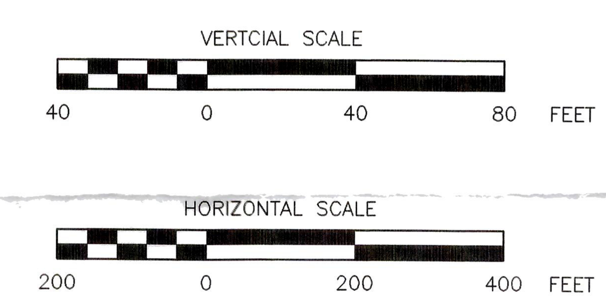
SECTION B–B'



SECTION C–C'



SECTION D–D'



NOTES:

1. FOR POND SURFACE AND SIDE SLOPE COVER DETAILS SEE FIGURE 3.
2. POND BOTTOM INFERRED FROM 'CELL 4 PHASE A AND PHASE B PLAN', WESTERN ENGINEERING INC., (JANUARY 17, 1989).
3. SEE FIGURES 1 AND 2 FOR CROSS SECTIONS LOCATIONS
4. EXISTING GROUND SURFACES SHALL BE REGRADED TO CONSTRUCT THE COVER WITH A FINAL SURFACE THAT IS CONSISTENT WITH THE RECLAMATION COVER GRADING PLAN.

RECLAMATION COVER
CROSS SECTIONS & DETAILS
PREPARED FOR

ENERGY FUELS NUCLEAR
BLANDING, UTAH

TITAN Environmental

No.	DATE	ISSUE / REVISION	DWN. BY	CK'D BY	AP'D BY
1	8-12-96	ISSUED FOR RECLAMATION PLAN	K.G.	[signature]	[signature]

DATE:	8-12-96	FIGURE 4	DRAWING NUMBER 6111-E4	1
SCALE:	AS SHOWN			

APPENDIX A

Laboratory Test Data

Table 3.4-1

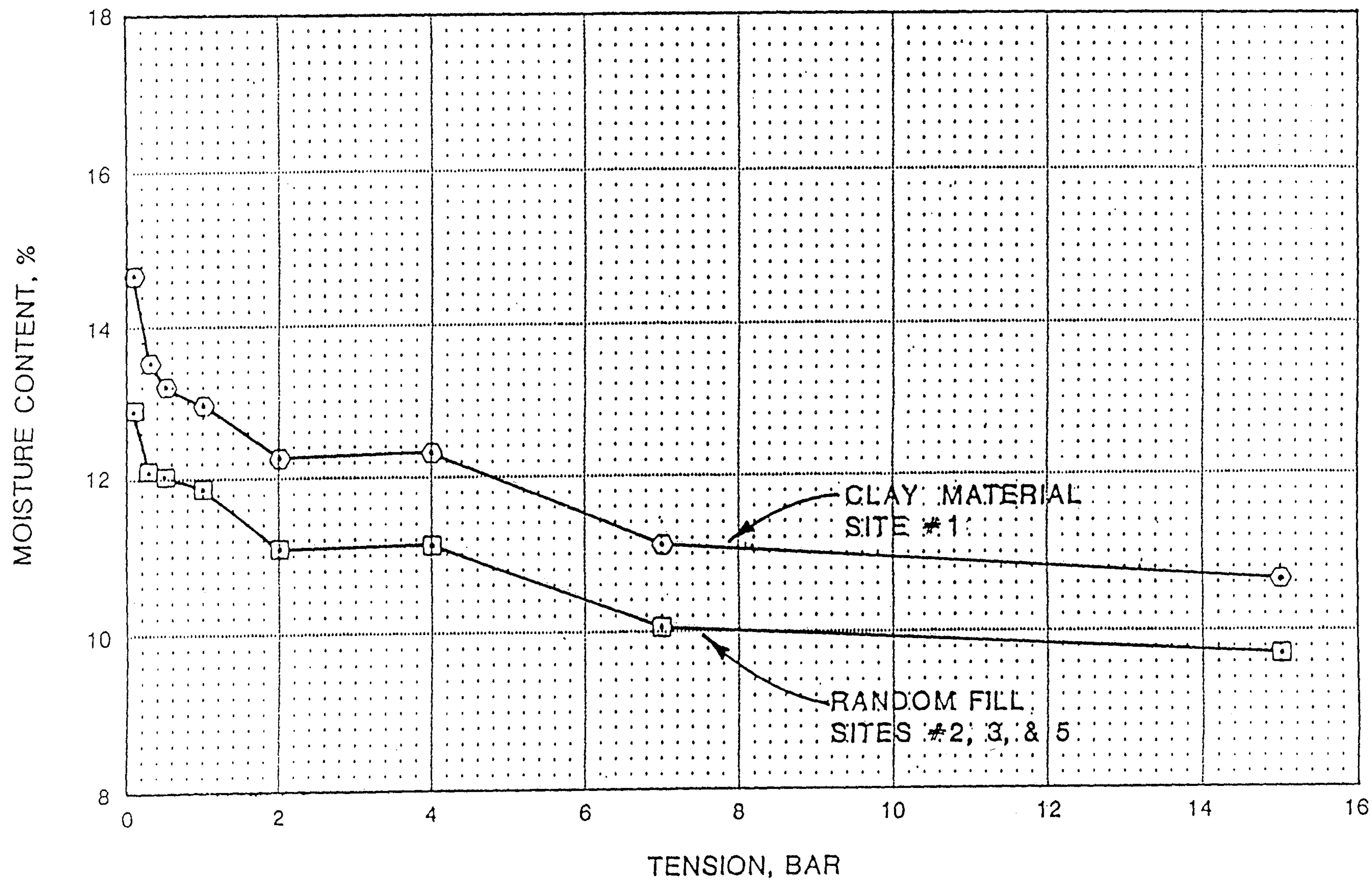
Physical Properties of Tailings

and

Proposed Cover Material

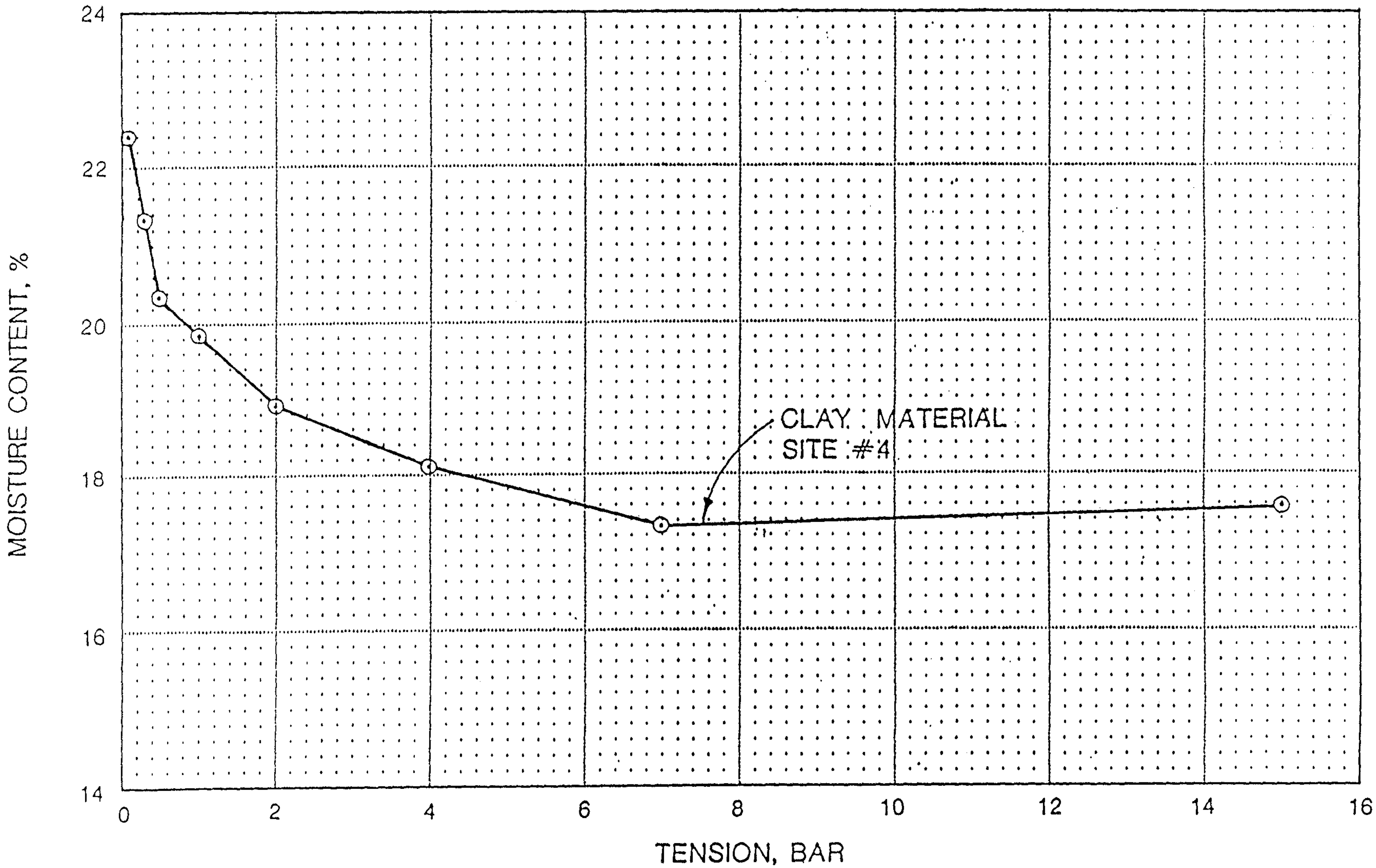
Material Type	Atterberg Limits LL	Atterberg Limits PI	Specific Gravity	% Passing No. 200 Sieve	Maximum Dry Density (pcf)	Optimum Moisture Content
Tailings	28	6	2.85	46	104.0	18.1
Random Fill	22	7	2.67	48	120.2	11.8

Note: Physical Soil Data from Chen and Associates (1987).



SUMMARY OF CAPILLARY MOISTURE
RELATIONSHIP TEST RESULTS
WHITE MESA PROJECT
FIGURE 3.5-1

DATA FROM CHEN & ASSOCIATES



SUMMARY OF CAPILLARY MOISTURE
RELATIONSHIP TEST RESULTS
WHITE MESA PROJECT
FIGURE 3.5-2

DATA FROM CHEN & ASSOCIATES;

SECTION 6

ROGERS AND ASSOCIATES ENGINEERING
CORPORATION

Letter Dated March 4, 1988
Letter Dated May 9, 1988

Radiological Properties

R
A
E

Rogers & Associates Engineering Corporation

Post Office Box 330
Salt Lake City, Utah 84110
(801) 263-1600

March 4, 1988

Mr. C.O.Sealy
Umetco Minerals Corporation
P.O. Box 1029
Grand Junction, CO 81502

C8700/22

Dear Mr. Sealy:

We have completed the tests ordered on the four samples shipped to us. The results are as follows:

Sample	Radium pCi/gm	Emanation Fraction	Diffusion Coeffic.	(g/cm^3) Density	Moisture	Saturation
Tailings	981±4	0.19±0.01	2.0E-02	1.45	13.2	0.39
			8.4E-03	1.44	19.1	0.56
Composite (2,3,&5)			1.6E-02	1.85	6.5	0.40
			4.5E-04	1.84	12.5	0.75
Site #1			1.6E-02	1.85	8.1	0.48
			1.4E-03	1.84	12.6	0.76
Site #4			1.1E-02	1.65	15.4	0.63
			4.2E-04	1.65	19.3	0.80

The samples will be shipped back to you in the next few weeks. If you have any questions regarding the results on the samples please feel free to call.

Sincerely,

Renee Y. Bowser
Lab Supervisor

RYB/b

R
A
E
Rogers & Associates Engineering Corporation

Post Office Box 330
Salt Lake City, Utah 84110
(801) 263-1600

MAY 12 1988

May 9, 1988

Mr. C.O. Sealy
UMETCO Minerals Corporation
P.O. Box 1029
Grand Junction, CO 81502

C8700/22

Dear Mr. Sealy:

The tests for radium content and radon emanation coefficient in the following samples have been completed and the results are as follows:

Sample	Radium (pCi/g)	Radon Emanation Coefficient
Random (2,3 & 5)	1.9 ± 0.1	0.19 ± 0.04
Site 1	2.2 ± 0.1	0.20 ± 0.03
Site 4	2.0 ± 0.1	0.11 ± 0.04

If you have any questions regarding these results please feel free to call Dr. Kirk Nielson or me.

Sincerely,

Renee Y. Bowser
Lab Supervisor

RYB:ms

515 East 4500 South • Salt Lake City, Utah 84107

ADVANCED TERRA TESTING inc.

833 Parfet Street
Lakewood, Colorado 80215
(303) 232-8308

ATTERBERG LIMITS TEST
ASTM D 4318

CLIENT	Titan Env.	JOB NO.	2234-04
BORING NO.		DATE SAMPLED	
DEPTH		DATE TESTED	7-25-96 WEB, RV
SAMPLE NO.	UT-1		
SOIL DESCR.			
TEST TYPE	ATTERBERG		

Plastic Limit Determination

	1	2	3
Wt Dish & Wet Soil	3.34	4.06	3.42
Wt Dish & Dry Soil	2.96	3.57	3.03
Wt of Moisture	0.38	0.49	0.39
Wt of Dish	1.05	1.11	1.06
Wt of Dry Soil	1.91	2.46	1.97
Moisture Content	19.90	19.92	19.80

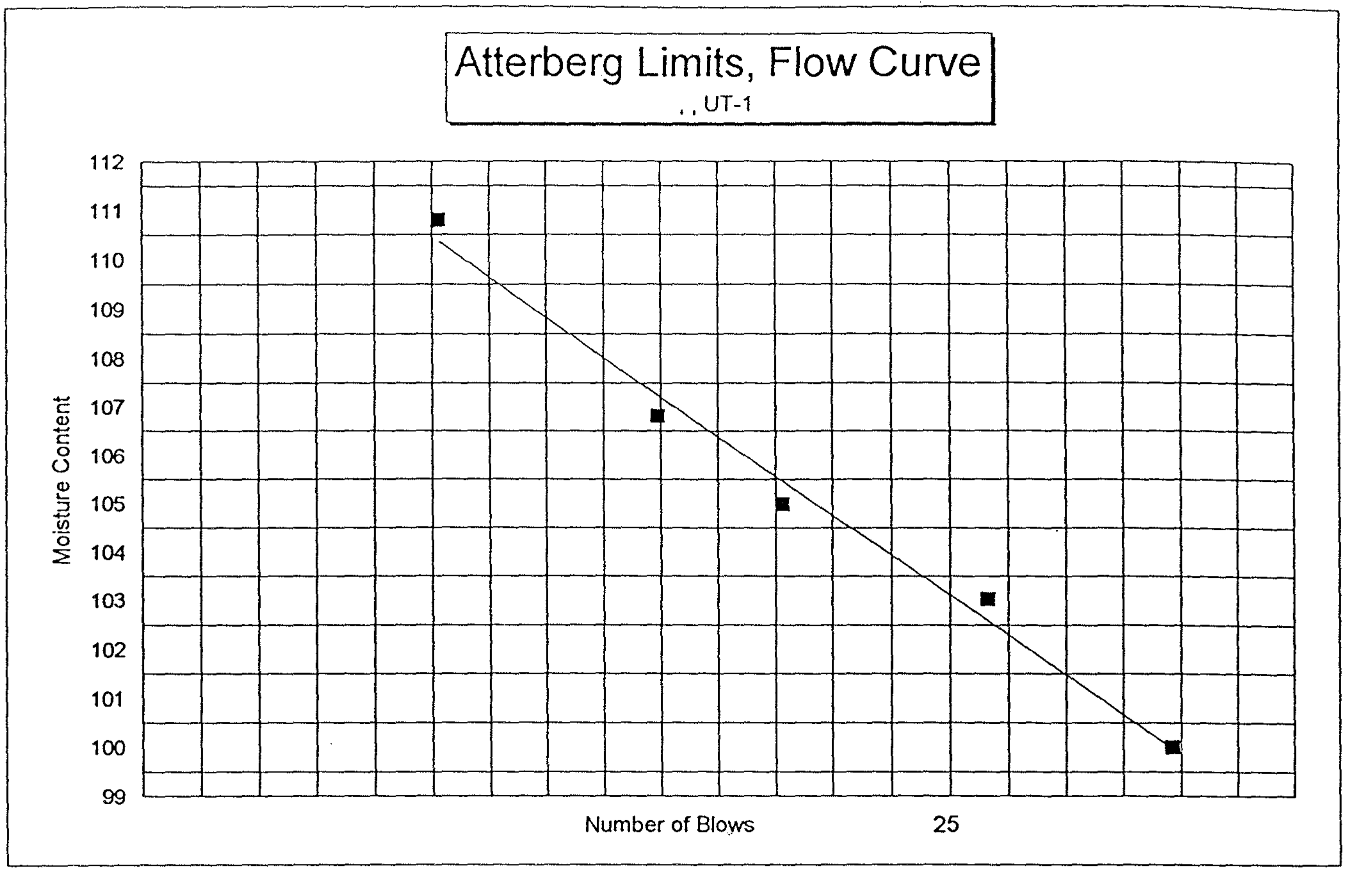
Liquid Limit Determination   Device Number   0258

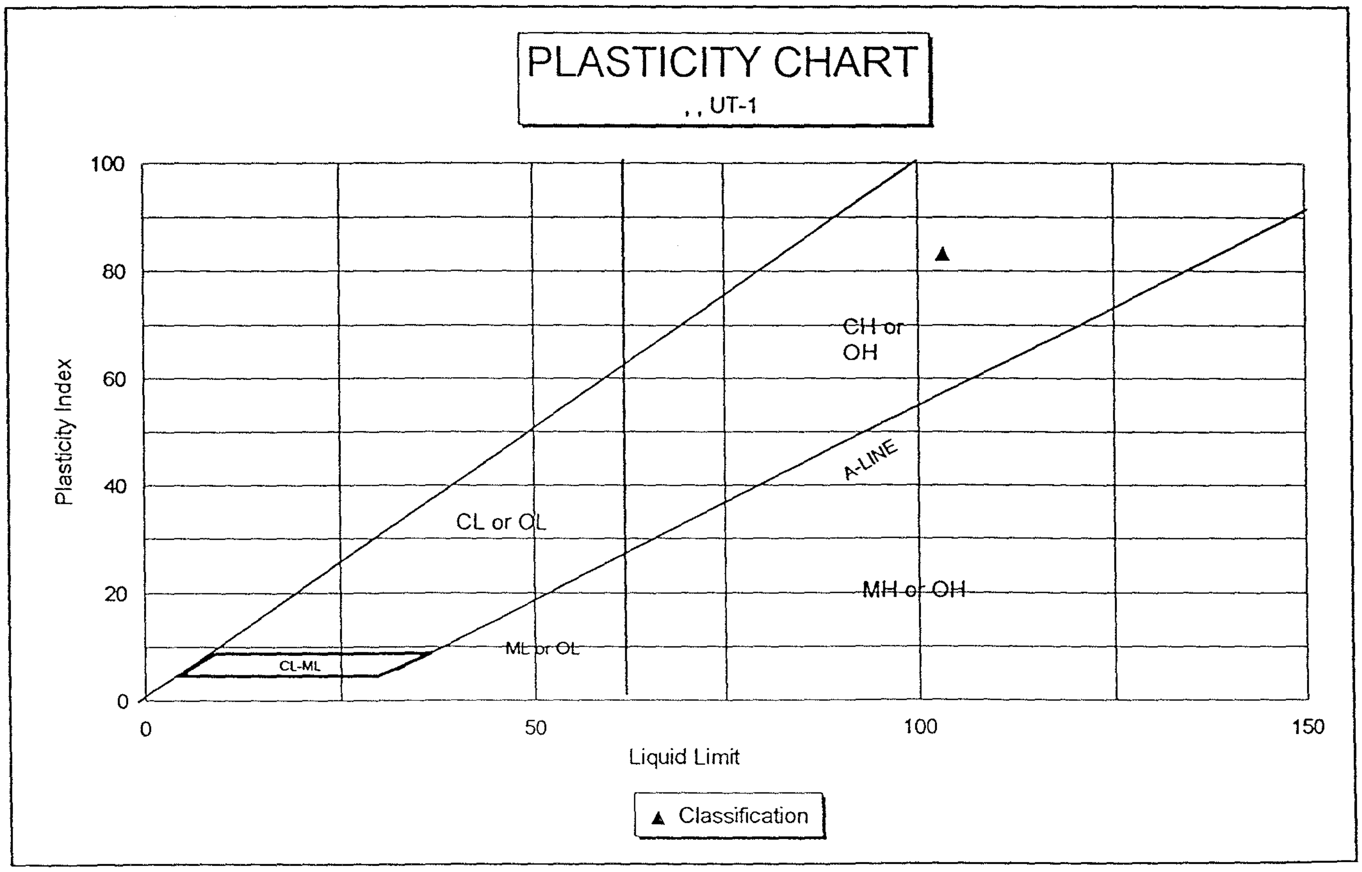
	1	2	3	4	5
Number of Blows	39	27	18	14	9
Wt Dish & Wet Soil	12.18	10.42	10.92	12.33	10.06
Wt Dish & Dry Soil	6.64	5.67	5.87	6.53	5.34
Wt of Moisture	5.54	4.75	5.05	5.80	4.72
Wt of Dish	1.10	1.06	1.06	1.10	1.08
Wt of Dry Soil	5.54	4.61	4.81	5.43	4.26
Moisture Content	100.00	103.04	104.99	106.81	110.80

Liquid Limit	103.1
Plastic Limit	19.9
Plasticity Index	83.3

Atterberg Classification CH

Data entry by: NAA   Date: 7-26-96
Checked by: [signature]   Date: 7-26-96
FileName: TIGOUT1   ADVANCED TERRA TESTING, INC.


Atterberg Limits, Flow Curve
, , UT-1
Moisture Content
112
111
110
109
108
107
106
105
104
103
102
101
100
99
Number of Blows
25


PLASTICITY CHART
, , UT-1
Plasticity Index
100
80
60
40
20
0
CH or
OH
A-LINE
CL or OL
MH or OH
ML or OL
CL-ML
0
50
100
150
Liquid Limit
▲ Classification

COMPACTION TEST
ASTM D 1557 A

CLIENT: TItan Env. JOB NO. 2234-04

ᴾORING NO. SOIL DESCR.
.PTH DATE SAMPLED
SAMPLE NO. UT-1 DATE TESTED 7-25-96 RV

Moisture determination

	1	2	3	4	5
Wt of Moisture added (ml)	100.00	150.00	250.00	350.00	450.00
Wt. of soil & dish (g)	384.26	393.92	291.42	244.20	281.17
Dry wt. soil & dish (g)	350.60	355.61	251.40	202.69	225.04
Net loss of moisture (g)	33.66	38.31	40.02	41.51	56.13
Wt. of dish (g)	8.01	8.34	8.31	8.29	8.43
Net wt. of dry soil (g)	342.59	347.27	243.09	194.40	216.61
Moisture Content (%)	9.83	11.03	16.46	21.35	25.91
Corrected Moisture Content					

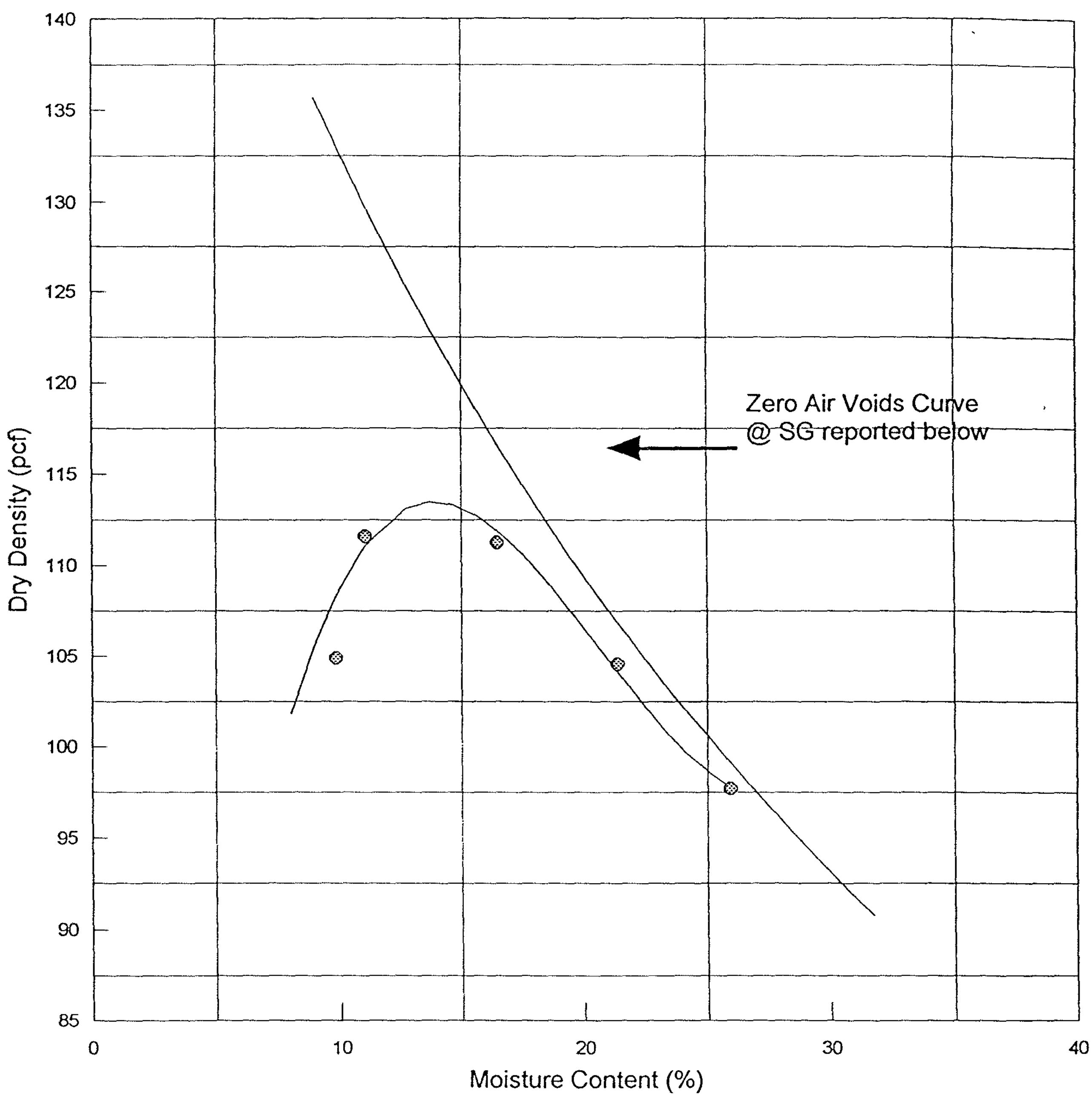
Density determination

Wt of soil & mold (lb)	14.20	14.49	14.68	14.59	14.46
Wt. of mold (lb)	10.36	10.36	10.36	10.36	10.36
Net wt. of wet soil (lb)	3.84	4.13	4.32	4.23	4.10
wt of dry soil (lb)	3.50	3.72	3.71	3.49	3.26
..y Density, (pcf)	104.89	111.59	111.28	104.57	97.69
Corrected Dry Density (pcf)					
Volume Factor	30	30	30	30	30

..ta entered by: RV Date: 7-26-96
..a checked by: [signature] Date: 7-26-96
FileName: TIPRUT-1 ADVANCED TERRA TESTING, INC

Proctor Compaction Test

, , UT-1



- Best Fit Curve
- Actual Data
- Zero Air VoidsCurve @ SG = 2.70

OPTIMUM MOISTURE CONTENT = 13.9 MAXIMUM DRY DENSITY = 113.5
ASTM D 1557 A, Rock correction applied? N

ADVANCED TERRA TESTING, INC.

PERMEABILITY DETERMINATION
FALLING HEAD
FIXED WALL

CLIENT	Titan Environmental	JOB NO.	2234-04
BORING NO.		SAMPLED	
DEPTH		TEST STARTED	7-28-96 CAL
SAMPLE NO.	UT-1	TEST FINISHED	8-7-96 CAL
SOIL DESCR.	Remolded 95% Mod Pt. @ OMC	SETUP NO.	1
SURCHARGE	200		

MOISTURE/DENSITY DATA	BEFORE TEST	AFTER TEST
Wt. Soil & Ring(s) (g)	386.9	404.5
Wt. Ring(s) (g)	93.0	93.0
Wt. Soil (g)	293.9	311.4
Wet Density PCF	122.3	120.5
Wt. Wet Soil & Pan (g)	302.4	319.9
Wt. Dry Soil & Pan (g)	266.2	266.2
Wt. Lost Moisture (g)	36.2	53.8
Wt. of Pan Only (g)	8.5	8.5
Wt. of Dry Soil (g)	257.7	257.7
Moisture Content %	14.1	20.9
Dry Density PCF	107.2	99.7
Max. Dry Density PCF	113.5	113.5
Percent Compaction	94.4	87.8

ELAPSED TIME (MIN)	BURETTE READING h1 (CC)	BURETTE READING h2 (CC)	PERCOLATION RATE FT/YEAR	PERCOLATION RATE CM/SEC
	0.2			
2599	10.8	10.8	0.14	1.4E-07
1427	14.2	14.2	0.09	8.4E-08
1440	16.8	16.8	0.07	6.5E-08
1440	18.6	18.6	0.05	4.6E-08
1440	20.2	20.2	0.04	4.1E-08
1440	21.6	21.6	0.04	3.7E-08
1469	23.0	23.0	0.04	3.6E-08
1440		24.4	0.04	3.7E-08

Data Entered By: NAA Date: 8-8-96
Date Checked By: [signature] Date: 8-8-96
Filename:TIFHUT1

ADVANCED TERRA TESTING, INC.

R
A
E

Rogers & Associates Engineering Corporation

Post Office Box 330
Salt Lake City, Utah 84110-0330
(801) 263-1600 • FAX (801) 262-1527

September 3, 1996

Pamela Anderson
Titan Environmental Corporation
7939 E. Arapahoe Rd., Suite 230
Englewood, CO 80112

C9600/9

Dear Ms. Anderson:

Enclosed are the results from the radium content, specific gravity, and radon emanation and diffusion coefficient measurements that were performed on the sample sent to our laboratory. We will be returning the sample within the month.

If you have any questions or if we can be of further assistance, please call.

Sincerely,

Bret C. Rogers
Scientist

515 East 4500 South • Salt Lake City, UT 84107-2918
Additional Offices in: Idaho Falls, ID • Santa Fe, NM • Washington DC

Rogers & Associates Engineering Corporation

REPORT OF RADON DIFFUSION COEFFICIENT MEASUREMENTS
(TIME-DEPENDENT DIFFUSION TEST METHOD RAE-SQAP-3.6)

Report Date: 9/3/96
Contract: C9600/9
By: BCR
Date Received: 8/96

Sample Identification: Titan Environmental

Sample ID	Moisture (Dry Wt. %)	Density (g/cm^3)	Radon Diffusion Coefficient (cm^2/s)	Saturation (Mρ/P)	Specific Gravity (g/cm^3)
UT-1	14.5%	1.72	9.1E-03	0.89	2.39

RAE

Post Office Box 330
Salt Lake City • Utah 84110
(801) 263-1600

Rogers & Associates Engineering Corporation

REPORT OF RADIUM CONTENT AND EMANATION
COEFFICIENT MEASUREMENTS
(LAB PROCEDURE RAE-SQAP-3.1)

Report Date: 9/3/96
Contract: C9600/9
By: BCR
Date Received: 8/96

Sample Identification: Titan Environmental

Sample ID	Moisture (Dry Wt. %)	Radon Emanation Coefficient	Radium-226 (pCi/g)	Comments
UT-1	14.6%	0.22 ± 0.04	1.5 ± 0.3	

RAE

Post Office Box 330
Salt Lake City • Utah 84110
(801) 263-1600

chen and associates, inc.
CONSULTING ENGINEERS

SOIL & FOUNDATION ENGINEERING
96 S. ZUNI • DENVER, COLORADO 80223 • 303/744-7105
1924 EAST FIRST STREET • CASPER, WYOMING 82601 • 307/234-2126

SECTION 2

Extracted Data From

SOIL PROPERTY STUDY
EARTH LINED TAILINGS RETENTION CELLS
WHITE MESA URANIUM PROJECT
BLANDING, UTAH

Prepared for:

ENERGY FUELS NUCLEAR, INC.

PARK CENTRAL
1515 ARAPAHOE STREET
DENVER, COLORADO 80202

Job No. 16,406

July 18, 1978

TABLE I

SUMMARY OF LABORATORY TEST RESULTS

Test Hole	Depth (Ft.)	NATURAL Moisture Content (%)	NATURAL Dry Density (pcf)	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	ATTERBERG LIMITS Liquid Limit (%)	ATTERBERG LIMITS Plasticity Index (%)	GRADATION ANALYSIS Maximum Size	GRADATION ANALYSIS Passing #200 (%)	GRADATION ANALYSIS Less than 2 µ (%)	REMOLDED Dry Density (pcf)	REMOLDED Moisture Content (%)	PERMEABILITY ft./yr.	PERMEABILITY cm./sec.	Specific Gravity	Soil Type
2	0-5			117.5	10.8	20	3	#16	58	19	111.6	16.4	0.57	5.5×10^{-7}		Sandy Silt
3	7-8	7.2				21	6	#16	62							Sandy Clayey Silt
5	7½-10			104.1	18.5	33	8	3/4 In.	56	12	102.1	22.0	0.085	8.2×10^{-8}	2.65	Calcareous Silty Clay
6	1-2	10.3				25	7	#16	77							Sandy Clayey Silt
6	8½-9	6.1				27	8	#4	70							Sandy Clay
8	5-5½	13.1					NP	3/4 In.	62							Calcareous Sandy Silt
9	0-1	8.1					NP	#16	53							Sand - Silt
10	4-6½					24	10	#4	73							Sandy Clay
11	5½-6½	14.0				26	6	#16	65							Siltstone-Claystone
12	2-5			101.0	20.6	53	35	#16	88	59	95.0	18.3	0.068	6.6×10^{-8}	2.67	Weathered Claystone
13	7-8	13.1				39	13	#8	84							Calcareous Silt Clay
14	1-2	19.3				40	21	#4	89							Weathered Claystone
15	1½-4½			106.8	19.0	26	8	3/8 In.	65	27	103.4	18.0	0.012	1.2×10^{-8}	2.64	Mod. Calcareous Sandy Clay
17	2-3	11.4				19	4	#8	59							Sandy Silt
19	0-3			117.5	12.8	23	6	#16	70		109.9	12.4	0.035	3.4×10^{-8}		Sandy Clayey Silt
22	1-2	13.2				26	10	#4	73							Sandy Clay
23	1-3					48	24	#30	87							Weathered Claystone
23	6-8					61	30	#30	96							Claystone
25	1-3½	13.3				26	9	#4	57							Sandy Clay
26	4½-5	15.3				41	20	#4	91							Weathered Claystone
28	0-2	12.7				28	10	3/8 In.	72							Sandy Clay
29	2-3	8.5				19	2	#16	59							Sandy Silt
32	8-8½	5.6				23	6	#30	73							Sandy Clayey Silt
37	0-4			118.8	11.5	23	5	#8	72		110.5	11.5	0.63	6.1×10^{-7}		Sandy Clayey Silt
38	5-7			111.0	16.7	29	14	3/8 In.	69		102.4	17.9	0.041	4.0×10^{-8}		Sandy Clay
40	4-5½			110.0	16.2	26	9	#8	64	27	106.4	16.4	0.017	1.6×10^{-8}	2.65	Sandy Clay

TABLE I

SUMMARY OF LABORATORY TEST RESULTS

Test Hole	Depth (Ft.)	NATURAL Moisture Content (%)	NATURAL Dry Density (pcf)	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	ATTERBERG LIMITS Liquid Limit (%)	ATTERBERG LIMITS Plasticity Index (%)	GRADATION ANALYSIS Maximum Size	GRADATION ANALYSIS Passing #200 (%)	GRADATION ANALYSIS Less than 2 μ (%)	REMOLDED Dry Density (pcf)	REMOLDED Moisture Content (%)	PERMEABILITY ft./yr.	PERMEABILITY cm./sec.	Specific Gravity	Soil Type
40	9-9½	6.8				22	8	3/8 In.	60							Sandy Clay
42	13½-14½	7.6				26	10	3/8 In.	73							Sandy Clay
43	11-12	12.1				41	22	#4	86							Claystone
43	13½-16½			110.0	16.9	40	24	3/8 In.	85	44	104.1	15.8	0.024	2.3×10^{-8}	2.62	Claystone
44	6½-7	7.5				30	11	3/8 In.	79							Calcareous Sandy Clay
46	0-2	12.3				22	6	#16	76							Sandy Clayey Silt
48	5-5½					30	9	3/8 In.	65							Sandy Clay
49	5-7			110.7	15.6	25	9	#16	71		105.2	13.9	0.33	3.2×10^{-8}		Sandy Clay
49	14-15					28	5	#8	55							Calcareous Sandy Silt
54	0-2	12.1				23	9	#8	64							Sandy Clay
55	5-5½	7.8				28	14	#30	71							Sandy Clay
55	9½-10½					28	13	#4	71							Sandy Clay
58	5½-6	12.5				35	11	#4	75							Sandy, Silty Clay
61	0-1	11.5				21	4	#16	75							Sandy Silt
62	11-11½	8.1					NP	1 In.	34							Calcareous Sand & Silt
63	4-6					30	14	#8	68							Sandy Clay
65	1-2	9.0					NP	#16	44							Silty Sand
68	7½-8	8.6				28	13	#8	67							Sandy Clay
70	3½-4½	16.4				27	4	1½ In.	46							Calcareous Sand & Silt
72	0-2	12.2				22	8	#16	59							Sandy Clay
75	10-11	12.4				41	25	#4	75							Weathered Claystone
75	12-14					45	22	#16	93							Claystone

416,406

TABLE II

LABORATORY PERMEABILITY TEST RESULTS

Random Fill

Sample	Soil Type	Compaction: Dry Density (pcf)	Compaction: Moisture Content (%)	Compaction: % of ASTM D698	Surcharge Pressure (psf)	Permeability (Ft/Yr)	Permeability (Cm/
TH 2 @ 0'-5'	Sandy Silt	111.6	16.4	95	500	0.57	5.5x1
TH 5 @ 7½'-10'	Calcareous Silty Clay	102.1	22.0	101	500	0.085	8.2x1
TH 12 @ 2'-5'	Weathered Claystone	95.0	18.3	94	500	0.068	6.6x1
TH 15 @ 1½'-4½'	Calcareous Sandy Clay	103.4	18.0	97	500	0.012	1.2x1
TH 19 @ 0'-3'	Sandy, Clayey Silt	109.9	12.4	94	500	0.035	3.4x1
TH 37 @ 0'-4'	Sandy, Clayey Silt	110.5	11.5	93	500	0.63	6.1x1
TH 38 @ 5'-7'	Sandy Clay	102.4	17.9	92	500	0.041	4.0x1
TH 40 @ 4'-5½'	Sandy Clay	106.4	16.4	97	500	0.017	1.6x1
TH 43 @ 13½-16½'	Claystone	104.1	15.8	95	500	0.024	2.3x1
TH 49 @ 5'-7'	Sandy Clay	105.2	13.9	95	500	0.33	3.2x1

TABLE III

RESULTS OF ATTERBERG LIMITS

SAMPLE	SOIL TYPE	PERCENT PASSING NO. 200 SIEVE	ATTERBERG LIMITS Liquid Limit (%)	Plastic Limit (%)	Shrinkage Limit (%)	SHRINKAGE RATIO
2 @ 0 - 5'	Sandy Silt	58	20	17	17.	1.81
5 @ 7½ - 10'	Calcareous Silty Clay	56	33	25	25	1.62
15 @ 1½-4½'	Calcareous Sandy Clay	65	26	18	17.5	1.76
19 @ 0-3'	Sandy, Clayey Silt	70	23	17	18	1.80
26 @ 4½-5'	Weathered Claystone	91	41	21	12	1.90
38 @ 5 - 7'	Sandy Clay	69	29	15	14	1.89

chen and associates, inc.
CONSULTING ENGINEERS

SOIL & FOUNDATION ENGINEERING   96 S. ZUNI • DENVER, COLORADO 80223 • 303/744-7105

SECTION 3

Extracted Data From

SOIL PROPERTY STUDY
PROPOSED TAILINGS RETENTION CELLS
WHITE MESA URANIUM PROJECT
BLANDING, UTAH

Prepared for:

ENERGY FUELS NUCLEAR, INC.
1515 ARAPAHOE STREET
DENVER, COLORADO 80202

Job No. 17,130

January 23, 1979

CHEN AND ASSOCIATES

TABLE 1

SUMMARY OF LABORATORY TEST RESULTS

HOLE	DEPTH (FEET)	NATURAL MOISTURE (%)	NATURAL DRY DENSITY (PCF)	ATTERBERG LIMITS		UNCONFINED COMPRESSIVE STRENGTH (PSF)	TRIAXIAL SHEAR TESTS		PERCENT PASSING NO. 200 SIEVE	SOIL TYPE
				LIQUID LIMIT (%)	PLASTICITY INDEX (%)		DEVIATOR STRESS (PSF)	CONFINING PRESSURE (PSF)		
76	0 - 1	4.5		21	5				78	Sandy silt
	9.5 - 10	4.4			NP				26	Silty, gravelly sand
77	7.5 - 8	8.6		30	15				71	Sandy clay
79	0 - 1	4.1		20	5				83	Sandy silt
	5 - 5.5	5.5			NP				41	Calcareous sandy clay
80	4.5 - 7			39	20				78	Calcareous sandy clay
	8 - 8.5	10.1		40	20				86	Weathered claystone
81	3 - 4	6.3		26	8				64	Silty, sandy clay
83	4 - 6			24	7				64	Sandy, clayey silt
84	0 - 2			18	2				65	Sandy silt
	9 - 9.5	2.7			NP				27	Silty sand
86	8 - 8.5	2.6			NP				12	Sandstone
87	0 - 1	3.1		16	1				61	Sandy silt
89	0 - 3			21	5				66	Sandy silt
90	8 - 8.5	12.9		35	15				61	Weathered claystone
92	0 - 1	5.9		21	5				80	Sandy silt
94	5 - 5.5	13.7		27	10				68	Sandy clay
95	6 - 7			23	5				62	Sandy silt
96	0 - 2	5.2		21	4				79	Sandy silt
	8.5 - 9.5			32	6				66	Calcareous sandy clay
98	0 - 1	3.8		20	5				74	Sandy silt
	4 - 4.5	17.8		49	25				76	Weathered claystone
99	8 - 9.5			40	20				89	Weathered claystone

CHEN AND ASSOCIATES

TABLE I

SUMMARY OF LABORATORY TEST RESULTS

HOLE	DEPTH (FEET)	NATURAL MOISTURE (%)	NATURAL DRY DENSITY (PCF)	ATTERBERG LIMITS		UNCONFINED COMPRESSIVE STRENGTH (PSF)	TRIAXIAL SHEAR TESTS		PERCENT PASSING NO. 200 SIEVE	SOIL TYPE
				LIQUID LIMIT (%)	PLASTICITY INDEX (%)		DEVIATOR STRESS (PSF)	CONFINING PRESSURE (PSF)		
99	11 - 12	13.5		26	10				73	Claystone
100	0 - 1			17	NP				44	Silty sand
	5.5 - 6	12.0			NP				61	Sandstone-siltstone
102	6.5 - 7	16.7		30	8				79	Calcareous sandy clay
	13.5 - 14	9.5		23	6				87	Claystone-siltstone
103	10 - 10.5	7.0		28	12				57	Sandy clay
104	8 - 8.5	9.2		33	9				70	Calcareous sandy clay
105	0 - 1	5.4		22	6				77	Sandy silt
	6.5 - 7	4.5			NP				86	Sandy silt
106	5 - 5.5	10.4		28	6				59	Claystone-sandstone
107	7.5 - 9				NP				23	Sandstone
108	0 - 1	4.0		18	3				69	Sandy silt
	9.5 - 10	9.9		38	16				93	Claystone
109	4 - 5			25	7				75	Sandy, clayey silt
111	9 - 9.5	5.8		25	10				53	Claystone
113	5 - 8			40	20				84	Weathered claystone
	10.5 - 11			24	10				54	Claystone-sandstone
114	0 - 2			22	6				58	Sandy, clayey silt
115	4.5 - 6				NP				58	Calcareous
116	0 - 3			22	5				72	Sandy silt
	7 - 8			24	10				42	Claystone-sandstone
117	1 - 2	10.6		25	5				77	Sandy silt
118	0 - 2			25	6				77	Sandy silt

CHEN AND ASSOCIATES

TABLE I

SUMMARY OF LABORATORY TEST RESULTS

HOLE	DEPTH (FEET)	NATURAL MOISTURE (%)	NATURAL DRY DENSITY (PCF)	ATTERBERG LIMITS		UNCONFINED COMPRESSIVE STRENGTH (PSF)	TRIAXIAL SHEAR TESTS		PERCENT PASSING NO. 200 SIEVE	SOIL TYPE
				LIQUID LIMIT (%)	PLASTICITY INDEX (%)		DEVIATOR STRESS (PSF)	CONFINING PRESSURE (PSF)		
118	6.5 - 8.5			40	20				89	Weathered claystone
119	4.5 - 5	10.0		26	12				68	Sandy clay
120	1 - 2			25	8				69	Sandy, clayey silt
	5 - 5.5	15.5		29	10				78	Sandy clay
	11 - 11.5	11.6		42	24				90	Claystone
122	4 - 6			25	8				66	Sandy, silty clay
	14.5 - 15	6.4		26	8				66	Sandy clay
123	1 - 3			23	7				71	Sandy, clayey silt
124	4.5 - 5	6.0		23	7				69	Sandy, clayey silt
125	0 - 1	3.8		22	6				67	Sandy silt
127	5 - 6			54	34				89	Claystone
128	6 - 8			41	24				90	Claystone

.E II

LABORATORY PERMEABILITY TEST RESULTS

Sample	Classification	Compaction Dry Density (pcf)	Compaction Moisture Content (%)	% of ASTM D698	Surcharge Pressure (psf)	Permeability Ft./Yr.	Permeability Cm/Sec
TH 80 @ 4½-7'	Calcareous sandy clay -200=78; LL=39; PI=20	100.2	19.4	96	500	0.81	7.8×10^{-7}
TH 84 @ 0-2'	Sandy silt -200=65; LL=18; PI=2	113.8	11.7	96	500	4.45	4.3×10^{-6}
TH 96 @ 8½-9½'	Calcareous sandy clay -200=66; LL=32; PI=6	96.9	20.7	97	500	1.55	1.5×10^{-6}
TH 96 @ 8½-9½'	Calcareous sandy clay	95.7	20.3	96	500	26.90*	2.6×10^{-5}
TH 99 @ 8-9½'	Weathered claystone -200=89; LL=40; PI=20	99.8	18.5	95	500	0.22	2.1×10^{-7}
TH 100 @ 0-1'	Very silty sand -200=44; PI=NP	117.5	9.7	98	500	0.38	3.7×10^{-7}
TH 114 @ 0-2'	Sandy, clayey silt -200=58; LL=22; PI=6	112.4	12.9	95	500	0.60	5.8×10^{-7}
TH 120 @ 1-2'	Sandy, clayey silt -200=69; LL=24; PI=6	108.2	14.7	95	500	0.11	1.1×10^{-7}
TH 122 @ 4-6'	Sandy, silty clay -200=66; LL=25; PI=8	108.8	15.5	96	500	0.43	4.2×10^{-7}
TH 123 @ 1-3'	Sandy, clayey silt -200=71; LL=23; PI=7	110.9	12.6	95	500	0.56	5.4×10^{-7}
TH 128 @ 6-7'	Claystone -200=89; LL=41; PI=24	92.4	23.9	93	500	0.12	1.2×10^{-7}
TH 128 @ 6-7'	Claystone -200=89; LL=41; PI=4	93.1	22.1	94	500	0.52*	5.0×10^{-7}*

* 1.5 pH sulfuric acid liquor used during percolation test interval.

MRAP - 710002387 - GEOTECHNICAL DATA BASE FOR MONTICELLO MILLSITE CHARACTERIZATION - R.N. MORRIS: CREATED 09/30/91; LAST UPDATED 11/22/91

AREA	DATA SOURC	BORING OR TEST PIT NUMBER	SAMPLE NUMBER & TYPE	TOP OF SAMPLE (FEET)	BASE OF SAMPLE (FEET)	SAMPLE MIDPOINT (FEET)	USCS SYMBOL	MATERIAL TYPE	IN-PLACE DRY DENSITY (PCF)	NATURAL MOISTURE CONTENT (PERCENT)	SPECIFIC GRAVITY	FRACTION PASSING #4 SIEVE (PERCENT)	FRACTION PASSING #200 SIEVE (PERCENT)	LIQUID LIMIT	PLASTICITY INDEX	ASTM D 698 MAXIMUM DRY DENSITY (PCF)	ASTM D 698 OPTIMUM MOISTURE CONTENT (PERCENT)	OTHER TESTS
CARBONATE PILE	BENDIX	MRAP-85-01	MKB-682/ST	6.0	8.0	7.00	CL-ML(?)	Tails-slm(?)	89.8	4.5	2.57	100.0	97.0	NP	NP	NA	NA	Consol w/perm, CMR @15 bar
CARBONATE PILE	BENDIX	MRAP-85-02	MKB-681/ST	2.0	4.0	3.00	SM	Tails-snd	107.5	4.0	2.60	100.0	46.0	NP	NP	NA	NA	Consol w/perm, CMR @15 bar
CARBONATE PILE	BENDIX	MRAP-85-02*	MKB-757/BULK	1.0	1.0	1.00	ML	Cover	NA	NA	NA	100.0	66.0	NA	NA	114.7	14.6	
CARBONATE PILE	BENDIX	MRAP-85-02*	MKB-758/BULK	3.0	3.0	3.00	SP	Tails-snd	NA	NA	NA	NA	NA	NA	NA	102.8	13.6	
CARBONATE PILE	BENDIX	MRAP-85-02*	MKB-759/BULK	6.0	6.0	6.00	SC(?)	Tails-slm	NA	NA	2.70	NA	NA	NA	NA	94.8	26.3	
CARBONATE PILE	BENDIX	MRAP-85-02	MKB-749/ST	2.0	4.0	3.00	CL-ML	Tails-slm&snd	92.1	27.4	2.57	100.0	84.0	26.0	4.6	NA	NA	Consol w/perm, CMR @15 bar
CARBONATE PILE	D&M	31SW91-046	1/SS	2.0	4.0	3.00	CL	Tails-slm	NA	33.8	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	2/SS	4.5	6.0	5.25	SP-SM	Tails-snd	NA	3.3	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	3/SS	6.0	8.0	7.00	SP-SM	Tails-snd	NA	5.4	2.63	100.0	11.4	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	4/SS	10.0	12.0	11.00	SP-SM	Tails-snd	NA	4.5	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	6/SS	13.0	14.0	13.50	SM	Tails-snd	NA	5.5	NA	100.0	18.1	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	7/SS	14.0	16.0	15.00	SM	Tails-snd	NA	14.4	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	8/SS	17.4	18.0	17.70	CL/ML/SM	Tails-snd/slm	NA	27.8	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	9/SS	19.5	20.0	19.75	SM	Tails-snd	NA	3.7	2.66	100.0	15.5	NP	NP	NA	NA	
CARBONATE PILE	D&M	31SW91-046	10/SS	20.2	22.0	21.10	SM	Tails-snd	NA	8.3	NA	100.0	23.5	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	13/SS	26.2	28.2	27.20	SM	Tails-snd	NA	5.8	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	14/SS	28.2	30.0	29.15	SM	Tails-snd	NA	8.6	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	15/SS	31.2	31.8	31.50	ML/SM	Tails-snd/slm	NA	38.9	NA	NA	NA	NP	NP	NA	NA	
CARBONATE PILE	D&M	31SW91-046	16/SS	32.7	34.0	33.35	CL/ML/SM	Tails-snd/slm	NA	21.8	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	17/SS	33.6	36.0	34.80	CL/ML/SM	Tails-snd/slm	NA	22.9	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	18/SS	36.4	38.0	37.00	SP-SM	Tails-snd	NA	24.2	2.70	100.0	9.7	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	19/SS	40.0	42.0	41.00	SM	Tails-snd&slm	NA	23.2	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	20/SS	43.0	44.0	43.50	SM	Tails-snd&slm	NA	25.2	NA	100.0	14.9	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	21/SS	44.5	46.4	45.15	CL	Alluvium	NA	28.9	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	22/SS	46.4	47.5	46.95	CL	Alluvium	NA	28.8	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	23/SS	48.0	50.0	49.00	CL	Alluvium	NA	23.8	NA	NA	NA	33.9	18.3	NA	NA	
CARBONATE PILE	D&M	31SW91-046	24/SS	51.0	52.0	51.50	CL	Alluvium	NA	23.0	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	25/SS	52.0	52.3	52.15	CL	Alluvium	NA	28.6	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	26/SS	54.5	56.0	55.25	CL	Alluvium	NA	56.6	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	28/SS	3.0	4.2	3.60	SC/CL	Cover(?)	NA	10.9	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	30/SS	4.2	5.0	4.60	SM	Tails-snd	NA	12.4	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-046	40/SS	8.0	10.0	9.00	CL	Alluvium	NA	20.1	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-080a	2/SS	3.5	5.5	4.50	SM	Tails-snd(Cover?)	NA	21.7	NA	84.2	12.5	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-080a	3/ST	5.5	7.5	6.50	SM	Tails-snd	88.8	21.4	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-080a	5/SS	10.0	10.5	10.25	SP-SM	Tails-snd	NA	21.3	NA	100.0	7.0	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-051	2/ST	8.5	9.0	8.75	SP-SM	Tails-snd	93.5	7.2	NA	100.0	10.2	NA	NA	NA	NA	Triax-CUPP
CARBONATE PILE	D&M	31SW91-051	4/ST	13.0	15.5	14.25	SM	Tails-snd	82.5	8.8	NA	100.0	21.8	NA	NA	NA	NA	Triax-CUPP, Perm
CARBONATE PILE	D&M	31SW91-051	5/ST	18.0	20.5	19.25	SM	Tails-snd	87.1	7.1	NA	100.0	18.3	NA	NA	NA	NA	Triax-CUPP
CARBONATE PILE	D&M	31SW91-051	8/SS	33.0	35.0	34.00	SM	Tails-snd	NA	11.9	2.75	100.0	14.6	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-051	9/SS	38.0	39.5	38.75	SP	Tails-snd	NA	25.8	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-051	11/SS	43.5	44.4	43.95	CL	Alluvium	NA	25.5	NA	NA	NA	38.1	18.1	NA	NA	
CARBONATE PILE	D&M	31SW91-051	12/SS	48.2	49.5	48.85	CL	Alluvium	NA	24.8	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-052	1/SS	4.2	6.0	5.10	SM/CL	Tails-snd/slm	NA	7.7	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-052	2/SS	8.5	10.2	9.35	CL	Tails-slm	NA	21.1	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-052	3/SS	15.0	16.0	15.50	SM	Tails-snd	NA	8.2	NA	100.0	14.9	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-052	4/SS	19.0	20.0	19.50	SM	Tails-snd	NA	8.5	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-052	8/SS	29.2	31.0	30.10	CL	Alluvium	NA	37.8	2.58	NA	NA	48.0	23.9	NA	NA	
CARBONATE PILE	D&M	31SW91-052	9/SS	34.0	36.0	35.00	CL	Alluvium	NA	9.2	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-052	10/SS	39.0	41.0	40.00	CL	Alluvium	NA	22.2	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-052	12/SS	49.0	51.0	50.00	CL	Alluvium	NA	28.8	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-058	1/SS	4.5	5.5	5.00	SM	Tails-snd	NA	12.4	2.69	100.0	35.7	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-058	5/SS	19.0	19.4	19.20	CL	Alluvium	NA	15.5	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-058	6/SS	24.0	26.0	25.00	CL	Alluvium	NA	19.8	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-058	7/SS	29.0	31.0	30.00	CL	Alluvium	NA	19.4	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	31SW91-058	8/SS	34.5	35.0	34.75	Km	Shale	NA	3.5	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	TP-4	1/ST	3.5	4.0	3.75	SM	Tails-snd	98.1	4.7	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	TP-4	4/BULK	4.5	4.5	4.50	SM	Tails-snd	NA	5.1	NA	NA	NA	NP	NP	101.8	17.2	Consol, Perm
CARBONATE PILE	D&M	TP-4	2/ST	8.0	8.5	8.25	ML	Tails-slm(?)	88.3	20.2	NA	NA	NA	21.5	8.2	NA	NA	
CARBONATE PILE	D&M	TP-4	3/ST	9.0	9.5	9.25	ML	Tails-slm(?)	71.0	35.4	NA	NA	NA	NA	NA	NA	NA	

TAS
10/6/94

144

MRAP - 710002307 - GEOTECHNICAL DATA ...SE FOR MONTICELLO MILLSITE CHARACTER...TION - R.N. MORRIS; CREATED 09/30/91; LAST UPDATED 11/22/91

AREA	DATA SOURC	BORING OR TEST PIT NUMBER	SAMPLE NUMBER & TYPE	TOP OF SAMPLE (FEET)	BASE OF SAMPLE (FEET)	SAMPLE MIDPOINT (FEET)	USCS SYMBOL	MATERIAL TYPE	IN-PLACE DRY DENSITY (PCF)	NATURAL MOISTURE CONTENT (PERCENT)	SPECIFIC GRAVITY	FRACTION PASSING #4 SIEVE (PERCENT)	FRACTION PASSING #200 SIEVE (PERCENT)	LIQUID LIMIT	PLASTICITY INDEX	ASTM D 698 MAXIMUM DRY DENSITY (PCF)	ASTM D 698 OPTIMUM MOISTURE CONTENT (PERCENT)	OTHER TESTS
CARBONATE PILE	D&M	TP-6	4/ST	10.5	11.0	10.75	CL	Talis-slm	70.6	48.3	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	TP-6	6/ST	17.0	17.5	17.25	SM	Talis-snd	73.3	19.6	NA	NA	NA	NA	NA	NA	NA	
CARBONATE PILE	D&M	TP-6	-/BULK	18.0	18.0	18.00	SM	Talis-snd(?)	NA	18.5	NA	100.0	46.4	NA	NA	96.1	18.9	
CARBONATE PILE	D&M	TP-11	-/BULK	6.0	6.0	6.00	SM	Talis-snd(?)	NA	18.7	2.78	100.0	47.8	NA	NA	103.7	18.0	Dir Shear, Perm, Mod Proct
CARBONATE PILE	D&M	TP-11	-/BULK	15.0	15.0	15.00	CL	Talis-slm	NA	53.1	NA	100.0	91.3	NA	NA	96.8	24.0	
VANADIUM PILE	BENDIX	MRAP-85-04	MKB-682/ST	4.0	6.0	5.00	SC	Talis-snd&slm	80.7	38.8	2.82	100.0	44.0	27.0	10.0	NA	NA	Consol w/perm, CMR @15 bar
VANADIUM PILE	BENDIX	MRAP-85-04*	MKB-753/BULK	1.0	1.0	1.00	ML	Cover	NA	NA	NA	NA	71.0	NA	NA	114.3	13.7	
VANADIUM PILE	BENDIX	MRAP-85-04*	MKB-754/BULK	2.0	2.0	2.00	SP	Talis-snd	NA	NA	2.67	NA	NA	NA	NA	107.8	13.2	
VANADIUM PILE	BENDIX	MRAP-85-04*	MKB-756/BULK	7.0	7.0	7.00	ML	Talis-slm	NA	NA	2.60	NA	NA	NA	NA	112.8	13.3	
VANADIUM PILE	BENDIX	MRAP-85-05	MKB-678/ST	8.0	8.0	8.00	CL-ML	Talis-slm	78.1	41.7	2.63	100.0	94.0	21.0	5.0	NA	NA	
VANADIUM PILE	D&M	315W91-031	3/ST	5.5	7.5	6.50	SM	Talis-snd	NA	9.4	2.89	100.0	21.4	18.1	17.1	NA	NA	Consol w/perm, CMR @15 bar
VANADIUM PILE	D&M	315W91-032	1/SS	2.0	3.5	2.75	SM/SC	Cover	NA	18.8	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	2/SS	3.5	5.0	4.25	SM/CL	Talis-snd/slm	NA	18.8	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	3/SS	5.0	6.5	5.75	SM	Talis-snd(?)	NA	15.0	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	4/SS	8.5	10.0	9.25	ML	Talis-slm	NA	34.1	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	6/SS	10.0	11.5	10.75	SM	Talis-snd&slm	NA	11.6	2.68	100.0	21.5	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	7/SS	11.5	13.0	12.25	ML	Talis-slm	NA	25.0	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	9/SS	15.0	16.5	15.75	SM/CL	Talis-snd/slm	NA	28.0	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	10/SS	16.5	18.0	17.25	SM/CL	Talis-snd/slm	NA	16.3	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	11/SS	18.0	19.5	18.75	CL	Alluvium	NA	20.9	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	12/SS	19.5	21.5	20.50	CL	Alluvium	NA	18.7	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	13/SS	21.5	23.5	22.50	CL	Alluvium	NA	20.1	NA	NA	NA	44.2	24.0	NA	NA	
VANADIUM PILE	D&M	315W91-032	14/SS	24.0	25.0	24.50	CL	Alluvium	NA	18.0	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	15/SS	25.5	27.5	26.50	CL	Alluvium	NA	23.9	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	16/SS	27.5	29.5	28.50	CL	Alluvium	NA	17.6	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	17/SS	29.5	31.5	30.50	CL	Alluvium	NA	17.9	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	18/SS	31.5	33.5	32.50	CL	Alluvium	NA	18.5	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	19/SS	33.5	34.8	34.15	CL	Alluvium	NA	17.6	NA	NA	NA	37.9	19.1	NA	NA	
VANADIUM PILE	D&M	315W91-032	20/SS	35.5	37.5	36.50	CL	Alluvium	NA	23.7	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	21/SS	37.5	39.5	38.50	CL	Alluvium	NA	22.2	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	22/SS	39.5	41.0	40.25	CL	Alluvium	NA	23.1	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	23/SS	41.5	42.8	42.15	SC/CL	Alluvium	NA	23.2	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	24/SS	43.5	44.9	44.20	GC	Alluvium	NA	18.9	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-032	25/SS	48.5	48.9	48.70	Km	Shale	NA	18.6	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-40b	5/ST	6.0	7.5	6.75	CL	Talis-slm	95.1	25.3	NA	NA	NA	45.7	24.9	NA	NA	Perm, CMR
VANADIUM PILE	D&M	315W91-40b	6/SS	13.5	14.8	14.15	CL	Talis-slm	NA	20.3	2.80	NA	NA	46.7	22.5	NA	NA	
VANADIUM PILE	D&M	315W91-40b	9/SS	18.5	20.5	19.50	CL	Talis-slm	NA	18.4	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-40b	11/SS	23.5	25.3	24.40	CL	Talis-slm	NA	23.4	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-041	1/SS	5.0	6.0	5.50	CL	Talis(?)-slm(?)	NA	22.8	NA	NA	NA	31.7	14.0	NA	NA	
VANADIUM PILE	D&M	315W91-041	2/SS	10.0	11.0	10.50	CL	Alluvium	NA	21.3	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-041	3/SS	14.0	16.0	15.00	CL	Alluvium	NA	18.8	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-041	4/SS	24.0	26.0	25.00	CL	Alluvium	NA	14.8	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-041	7/SS	29.0	31.0	30.00	CL	Alluvium	NA	19.3	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-041	8/SS	34.5	36.0	35.25	CL	Alluvium	NA	27.7	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-041	9/SS	38.0	40.0	39.00	SC	Alluvium	NA	13.2	NA	100.0	40.1	NA	NA	NA	NA	
VANADIUM PILE	D&M	315W91-041	10/SS	44.0	44.5	44.25	Kd	Sandstone	NA	5.3	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	TP-5	1/ST	4.5	5.0	4.75	SM	Talis-snd	90.1	7.4	NA	NA	NA	NP	NP	NA	NA	
VANADIUM PILE	D&M	TP-5	2/ST	5.5	6.0	5.75	CL	Talis-slm	76.7	51.6	NA	NA	NA	NA	NA	NA	NA	Unconf Comp
VANADIUM PILE	D&M	TP-5	4/ST	9.0	9.5	9.25	CL	Talis-slm	71.0	48.7	NA	NA	NA	NA	NA	NA	NA	Unconf Comp
VANADIUM PILE	D&M	TP-5	5/ST	11.0	11.5	11.25	CL	Talis-slm	84.8	16.5	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	TP-5	7/ST	14.0	14.5	14.25	CL	Talis(?)-slm(?)	48.5	51.8	NA	NA	NA	NA	NA	NA	NA	
VANADIUM PILE	D&M	TP-12	-/BULK	6.0	6.0	6.00	CL	Talis-slm	NA	24.3	2.75	NA	NA	29.2	12.5	115.0	14.0	Perm, Mod Proct
VANADIUM PILE	D&M	TP-12	-/BULK	12.0	12.0	12.00	CL	Talis-slm	NA	33.9	2.84	NA	NA	44.7	20.5	102.7	21.2	Triax-CU/PP, Perm, Mod Proct, CMR
EAST PILE	BENDIX	MRAP-85-08	MKB-688/ST	2.0	4.0	3.00	SM	Talis-snd	98.4	5.2	2.67	100.0	42.0	NP	NP	NA	NA	Consol w/perm, CMR @15 bar
EAST PILE	BENDIX	MRAP-85-08*	MKB-775/BULK	1.0	1.0	1.00	ML	Cover	NA	NA	NA	100.0	52.0	NA	NA	111.2	14.1	
EAST PILE	BENDIX	MRAP-85-08*	MKB-780/BULK	3.0	3.0	3.00	SM(?)	Talis-snd	NA	NA	NA	NA	NA	NA	NA	107.1	15.3	
EAST PILE	BENDIX	MRAP-85-08*	MKB-782/BULK	15.0	15.0	15.00	SP(?)	Talis-snd(?)	NA	NA	2.70	NA	NA	NA	NA	103.8	15.5	
EAST PILE	BENDIX	MRAP-85-07	MKB-687/ST	2.0	4.0	3.00	SM	Talis-snd	94.0	9.9	2.81	100.0	19.0	NP	NP	NA	NA	Consol w/perm, CMR @15 bar
EAST PILE	BENDIX	MRAP-85-08	MKB-714/ST	12.0	14.0	13.00	CL	Talis-slm	108.6	34.4	2.70	100.0	81.0	41.0	22.0	NA	NA	Consol w/perm, CMR @15 bar
EAST PILE	BENDIX	MRAP-85-09	MKB-708/ST	4.0	6.0	5.00	ML	Talis-slm	100.7	21.4	2.83	100.0	84.0	42.0	13.0	NA	NA	Consol w/perm, CMR @15 bar
EAST PILE	D&M	315W91-002	1/SS	3.5	5.5	4.50	SP	Talis-snd	NA	12.8	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	315W91-002	2/SS	8.5	10.5	9.50	SM/ML	Talis-snd/slm	NA	18.8	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	315W91-002	3/SS	13.5	15.5	14.50	SM/ML	Talis-snd/slm	NA	15.3	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	315W91-002	NA	24.0	25.0	24.50	CL	Alluvium	NA	18.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	315W91-002	10/SS	28.0	30.0	29.00	CL	Alluvium	NA	18.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	315W91-003	1/SS	7.0	8.3	7.65	ML	MVP spoil	NA	7.2	NA	NA	NA	NA	NA	NA	NA	

/20

154

MRAP - 710002307 - GEOTECHNICAL DATA BASE FOR MONTICELLO MILLSITE CHARACTERIZATION - R.N. MORRIS; CREATED 09/30/91; LAST UPDATED 11/22/91

AREA	DATA SOURC	BORING OR TEST PIT NUMBER	SAMPLE NUMBER & TYPE	TOP OF SAMPLE (FEET)	BASE OF SAMPLE (FEET)	SAMPLE MIDPOINT (FEET)	USCS SYMBOL	MATERIAL TYPE	IN-PLACE DRY DENSITY (PCF)	NATURAL MOISTURE CONTENT (PERCENT)	SPECIFIC GRAVITY	FRACTION PASSING #4 SIEVE (PERCENT)	FRACTION PASSING #200 SIEVE (PERCENT)	LIQUID LIMIT	PLASTICITY INDEX	ASTM D 698 MAXIMUM DRY DENSITY (PCF)	ASTM D 698 OPTIMUM MOISTURE CONTENT (PERCENT)	OTHER TESTS
EAST PILE	D&M	31SW91-003	9/SS	20.5	22.0	21.25	CL	Tails-slm	NA	58.2	NA	NA	NA	48.4	22.5	NA	NA	
EAST PILE	D&M	31SW91-003	11/SS	24.5	26.0	25.25	CL/SM	Tails-snd/slm	NA	34.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-003	12/SS	26.5	28.0	27.25	CL/SM/ML	Tails-snd/slm	NA	50.1	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-003	13/SS	28.5	30.0	29.25	ML	Tails-snd&slm	NA	28.7	NA	100.0	71.5	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-003	19/SS	40.0	40.5	40.25	ML	Alluvium	NA	24.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-003	20/SS	42.0	42.7	42.35	ML	Alluvium	NA	23.8	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-003	21/SS	46.0	47.5	46.75	ML	Alluvium	NA	25.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-003	22/SS	48.0	49.7	48.85	ML	Alluvium	NA	24.8	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-004	1/SS	3.5	5.0	4.25	CL	MVP spoil	NA	18.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-004	2/SS	9.5	10.0	9.75	SM	Tails-snd	NA	28.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-004	3/U	14.5	15.0	14.75	CL	Tails-slm	82.1	33.1	NA	NA	NA	35.5	12.7	NA	NA	
EAST PILE	D&M	31SW91-004	4/U	19.5	20.0	19.75	CL	Alluvium	95.9	23.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-004	5/SS	23.5	25.0	24.25	CL	Alluvium	NA	18.8	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-004	6/SS	27.0	28.4	27.70	CL	Alluvium	NA	19.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-004	7/SS	28.5	30.0	29.25	CL	Alluvium	NA	18.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-004	8/SS	33.5	35.0	34.25	CL	Alluvium	NA	22.7	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-004	9/U	38.5	40.0	38.75	CL	Alluvium	100.2	22.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-008	1/U	4.5	5.0	4.75	SM	Tails-snd	99.2	7.0	NA	100.0	21.0	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-008	4/U	15.0	15.5	15.25	CL	Tails-slm	54.1	82.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-008	6/U	19.5	20.0	19.75	ML	Tails-slm	84.3	30.1	NA	NA	NA	23.2	2.8	NA	NA	Triax-CUPP
EAST PILE	D&M	31SW91-008	7/U	23.5	25.0	24.25	CH	Alluvium	87.3	57.4	NA	NA	NA	51.4	23.5	NA	NA	
EAST PILE	D&M	31SW91-008	9/U	28.5	30.0	29.25	CL	Alluvium	81.1	34.2	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-008	4/ST	16.0	17.5	16.75	CL	Tails-snd&slm	95.1	28.0	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-008	7/ST	20.0	22.0	21.00	CL	Tails-slm	60.0	64.3	NA	NA	NA	NA	NA	NA	NA	Unconf Comp, Consol, Perm, CMR
EAST PILE	D&M	31SW91-010a	1/SS	9.0	10.5	9.75	CL	Alluvium	NA	10.5	NA	NA	NA	34.8	18.6	NA	NA	
EAST PILE	D&M	31SW91-010a	3/SS	19.0	20.5	19.75	CL	Alluvium	NA	18.2	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-010a	4/SS	24.0	25.5	24.75	CL	Alluvium	NA	14.6	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-010a	5/SS	29.0	30.5	29.75	CL	Alluvium	NA	15.1	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-010b	3/SS	34.0	35.5	34.75	CL	Alluvium	NA	17.9	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-010b	4/SS	39.0	40.5	39.75	CL	Alluvium	NA	17.8	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-010b	5/SS	44.0	45.5	44.75	CL/SC	Alluvium	NA	21.1	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-010b	6/SS	49.0	49.5	49.25	SC	Alluvium	NA	12.7	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-012	3/ST	10.5	12.5	11.50	CL	Tails-slm	59.8	57.2	NA	NA	NA	NA	NA	NA	NA	Unconf Comp
EAST PILE	D&M	31SW91-012	8/ST	25.5	27.5	26.50	CL-ML	Tails-snd/slm	58.7	50.5	NA	NA	NA	NA	NA	NA	NA	Triax-CUPP, Consol
EAST PILE	D&M	31SW91-013	9/SS	28.5	30.5	29.50	CL/SM	Tails-snd/slm	NA	28.7	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-014	1/U	4.5	5.0	4.75	CL	MVP spoil	108.5	8.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-014	2/U	9.5	10.0	9.75	SM	Tails-snd	96.7	7.8	NA	100.0	22.0	NA	NA	NA	NA	Dir Shear
EAST PILE	D&M	31SW91-014	3/U	14.5	15.0	14.75	CL	Alluvium(?)	90.4	25.1	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-014	7/U	19.5	20.0	19.75	CL	Alluvium(?)	55.0	79.9	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-014	9/U	24.0	24.5	24.25	CL	Alluvium(?)	62.8	82.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-014	16/SS	48.0	49.3	48.65	Km	Shale	NA	13.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-015b	1/U	2.5	3.8	3.15	SM	Tails-snd	68.3	7.8	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-015b	2/U	7.5	8.8	8.15	SM	Alluvium	85.6	28.4	2.81	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-015b	3/U	12.5	13.7	13.10	CL/SC	Alluvium	NA	18.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-018	1/SS	5.5	6.5	6.00	ML	Tails-snd&slm(?)	NA	10.3	NA	100.0	56.4	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-018	3/SS	8.0	9.5	8.75	SM	Tails-snd	NA	12.4	NA	99.2	46.1	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-018	5/SS	11.0	12.5	11.75	SM	Tails-snd	NA	8.2	NA	99.5	30.8	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-018	6/SS	12.5	14.0	13.25	SM	Tails-snd	NA	5.0	NA	100.0	33.2	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-018	7/SS	14.0	15.5	14.75	SM	Tails-snd	NA	17.7	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-019	8/SS	15.5	17.0	16.25	SM	Tails-snd	NA	17.9	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-019	9/SS	17.0	18.5	17.75	CL	Tails-slm	NA	43.7	NA	NA	NA	35.0	13.8	NA	NA	
EAST PILE	D&M	31SW91-019	10/SS	18.5	20.0	19.25	CL	Tails-slm	NA	34.4	NA	NA	NA	44.7	18.3	NA	NA	
EAST PILE	D&M	31SW91-019	11/SS	20.0	21.5	20.75	CL	Alluvium(?)	NA	25.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-019	12/SS	21.5	23.0	22.25	CL	Alluvium(?)	NA	24.7	NA	NA	NA	39.0	19.0	NA	NA	
EAST PILE	D&M	31SW91-019	15/SS	33.0	33.5	33.25	SC	Alluvium	NA	5.7	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-020	1/SS	4.0	5.5	4.75	CL	Alluvium	NA	10.9	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-020	2/SS	9.0	10.5	9.75	CL	Alluvium	NA	13.2	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-020	3/SS	14.0	15.5	14.75	CL	Alluvium	NA	18.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-020	4/SS	19.0	20.5	19.75	CL	Alluvium	NA	13.5	NA	NA	NA	45.0	23.8	NA	NA	
EAST PILE	D&M	31SW91-020	5/SS	24.0	25.5	24.75	CL	Alluvium	NA	18.0	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-020	6/SS	29.0	30.5	29.75	SC	Alluvium	NA	21.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-020	7/SS	34.0	35.0	34.50	GC	Alluvium	NA	18.7	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-025	3/U	13.0	13.7	13.35	CL	Alluvium	101.8	22.9	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-025	4/U	18.0	19.5	18.75	CL	Alluvium	98.5	25.3	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-025	5/SS	23.5	24.8	24.15	SC(?)	Alluvium	97.9	23.2	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	31SW91-025	6/U	29.3	29.8	29.55	Km	Shale	113.4	16.1	NA	NA	NA	NA	NA	NA	NA	

1/20

194

MRAP - 710002307 - GEOTECHNICAL DATA BASE FOR MONTICELLO MILLSITE CHARACTERIZATION – R.N. MORRIS; CREATED 09/30/91; LAST UPDATED 11/22/91

AREA	DATA SOURC	BORING OR TEST PIT NUMBER	SAMPLE NUMBER & TYPE	TOP OF SAMPLE (FEET)	BASE OF SAMPLE (FEET)	SAMPLE MIDPOINT (FEET)	USCS SYMBOL	MATERIAL TYPE	IN-PLACE DRY DENSITY (PCF)	NATURAL MOISTURE CONTENT (PERCENT)	SPECIFIC GRAVITY	FRACTION PASSING #4 SIEVE (PERCENT)	FRACTION PASSING #200 SIEVE (PERCENT)	LIQUID LIMIT	PLASTICITY INDEX	ASTM D 698 MAXIMUM DRY DENSITY (PCF)	ASTM D 698 OPTIMUM MOISTURE CONTENT (PERCENT)	OTHER TESTS
EAST PILE	D&M	TP-1	1/ST	6.5	7.0	6.75	CL	MVP spoil	100.3	11.1	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	TP-1	-/BULK	7.0	7.0	7.00	CL	MVP spoil	NA	18.2	NA	NA	NA	NA	NA	103.1	18.1	Perm, Mod Proct
EAST PILE	D&M	TP-1	2/ST	9.0	9.5	9.25	CL	MVP spoil	86.2	20.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	TP-1	3/ST	14.0	14.5	14.25	SM	Tails-snd	101.3	7.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	TP-1	-/BULK	15.0	15.0	15.00	SM	Tails-snd	NA	10.8	NA	99.0	31.6	NA	NA	109.4	14.2	
EAST PILE	D&M	TP-2	1/ST	9.0	9.5	9.25	SM	Tails-slm	91.5	27.9	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	TP-2	-/BULK	10.0	10.0	10.00	ML	Tails-slm	NA	33.0	NA	NA	NA	NA	NA	103.0	20.0	Consol, CMR
EAST PILE	D&M	TP-2	2/ST	10.5	11.0	10.75	SM	Tails-snd	87.2	1.7	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	TP-2	3/ST	13.5	14.0	13.75	ML	Tails-snd&slm(?)	86.8	53.5	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	TP-2	-/BULK	14.0	14.0	14.00	ML	Tails-snd&slm(?)	NA	7.8	NA	100.0	54.4	NA	NA	103.6	17.1	CMR
EAST PILE	D&M	TP-2	4/ST	14.5	15.0	14.75	ML	Tails-snd&slm(?)	74.0	25.4	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	TP-4	-/BULK	9.0	9.0	9.00	ML	Tails-snd&slm	NA	32.4	NA	100.0	91.0	NA	NA	94.8	21.5	Dir Shear, Perm, CMR
EAST PILE	D&M	TP-4	3/ST	9.5	10.0	9.75	ML	Tails-snd&slm	81.5	7.9	NA	NA	NA	NA	NA	NA	NA	
EAST PILE	D&M	TP-4	-/BULK	14.0	14.0	14.00	ML	Tails-snd&slm	NA	14.7	2.71	100.0	96.5	NA	NA	101.8	17.3	Perm, CMR
EAST PILE	D&M	TP-4	5/ST	14.5	15.0	14.75	ML	Tails-snd&slm	81.8	57.1	NA	100.0	94.1	NA	NA	NA	NA	
ACID PILE	BENDIX	MRAP-86-10	MKB-723/ST	4.0	6.0	5.00	CL	Tails-slm	86.1	41.5	2.83	100.0	78.0	29.0	11.0	NA	NA	
ACID PILE	BENDIX	MRAP-86-10*	MKB-791/BULK	1.0	1.0	1.00	SM	Cover	NA	NA	NA	100.0	40.0	NA	NA	111.5	16.9	
ACID PILE	BENDIX	MRAP-86-10*	MKB-792/BULK	3.0	3.0	3.00	SP	Tails-snd	NA	NA	NA	NA	NA	NA	NA	110.4	12.4	
ACID PILE	BENDIX	MRAP-86-10*	MKB-793/BULK	5.0	5.0	5.00	CL	Tails-slm	NA	NA	2.78	NA	NA	NA	NA	94.5	26.3	
ACID PILE	BENDIX	MRAP-85-11	MKB-741/ST	4.0	6.0	5.00	CL	Tails-slm	74.8	38.8	2.68	100.0	72.0	44.0	20.0	NA	NA	Consol w/perm, CMR @15 bar
ACID PILE	BENDIX	MRAP-85-12	MKB-722/ST	4.0	6.0	5.00	ML	Tails-slm	78.4	40.5	2.68	100.0	87.0	47.0	10.0	NA	NA	Consol w/perm, CMR @15 bar
ACID PILE	D&M	315W91-026	1/SS	4.5	5.0	4.75	CL	Tails-snd&slm	NA	30.0	NA	NA	NA	33.5	13.1	NA	NA	
ACID PILE	D&M	315W91-026	2/SS	8.5	9.0	8.75	CL	Alluvium	NA	12.8	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-026	5/SS	13.5	14.5	14.00	CL	Alluvium	NA	17.1	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-027	3/ST	6.0	8.0	7.00	CH	Alluvium	71.5	48.0	NA	NA	NA	58.9	28.7	NA	NA	Triax-CUPP, Unconf Comp, Perm, CMR
ACID PILE	D&M	315W91-027	4/ST	9.0	11.5	10.25	CH	Alluvium	86.0	78.2	NA	NA	NA	66.5	31.4	NA	NA	Triax-CUPP, Unconf Comp, Consol
ACID PILE	D&M	315W91-027	6/ST	19.0	20.5	19.75	CL/SC	Alluvium	108.3	11.3	NA	NA	NA	37.4	21.0	NA	NA	Triax-CUPP, Unconf Comp, Perm, CMR
ACID PILE	D&M	315W91-028	2/SS	4.0	6.0	5.00	SM	Tails-snd(?)	NA	17.2	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	3/SS	6.0	6.9	6.45	SM	Tails-snd	NA	17.2	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	4/SS	9.0	10.0	9.50	CL-ML	Tails-slm	NA	37.6	2.70	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	5/SS	10.5	12.0	11.25	ML	Tails-slm	NA	38.5	NA	NA	NA	34.8	9.4	NA	NA	
ACID PILE	D&M	315W91-028	6/SS	13.5	15.0	14.25	ML	Tails-snd&slm	NA	27.9	NA	100.0	51.7	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	7/SS	15.0	17.0	16.00	SM	Tails-snd&slm	NA	18.5	NA	100.0	34.7	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	8/SS	18.0	19.0	18.50	ML	Tails-slm	NA	43.3	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	9/SS	19.0	21.0	20.00	ML	Tails-slm	NA	38.0	NA	100.0	65.9	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	10/SS	22.5	23.0	22.75	SM	Tails-snd	NA	80.0	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	11/SS	24.0	25.0	24.50	ML/CL	Tails-snd&slm	NA	53.1	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	12/SS	25.0	27.0	26.00	ML/CL	Tails-snd&slm	NA	98.3	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	13/SS	27.0	29.0	28.00	CL	Tails-snd&slm	NA	56.9	NA	100.0	92.0	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	14/SS	29.0	30.5	29.75	ML/CL	Tails-snd&slm	NA	51.4	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	15/SS	31.0	33.0	32.00	CL	Tails-snd&slm	NA	64.7	NA	NA	NA	48.8	21.2	NA	NA	
ACID PILE	D&M	315W91-028	16/SS	33.5	34.0	33.75	ML	Tails-snd&slm	NA	41.3	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	17/SS	36.0	37.0	36.50	ML/SC	Alluvium(?)	NA	19.1	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	18/SS	37.5	39.0	38.25	SC/CL	Alluvium	NA	20.9	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-028	19/SS	38.0	41.0	40.00	CL	Alluvium	NA	34.5	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-034	1/SS	5.0	6.0	5.50	ML/CL	Tails-slm	NA	57.3	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-034	3/SS	14.0	16.0	15.00	CL-ML	Tails-slm	NA	17.3	2.86	NA	NA	47.4	17.8	NA	NA	
ACID PILE	D&M	315W91-034	7/SS	29.0	29.5	29.25	Km	Shale	NA	10.1	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-035	3/SS	5.0	5.5	5.25	SM	Tails-snd	NA	4.8	NA	100.0	20.7	NA	NA	NA	NA	
ACID PILE	D&M	315W91-035	4/SS	10.0	10.5	10.25	SM	Tails-snd	NA	5.5	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	315W91-035	6/SS	15.0	15.5	15.25	SM	Tails-snd	NA	11.3	NA	100.0	28.0	NA	NA	NA	NA	
ACID PILE	D&M	315W91-035	9/ST	18.0	20.0	19.00	SM	Tails-snd	100.8	13.4	NA	100.0	17.2	NA	NA	NA	NA	Dir Shear, Perm, CMR
ACID PILE	D&M	315W91-035	12/SS	24.5	25.0	24.75	CL/ML	Tails-slm	NA	19.4	NA	NA	NA	46.0	18.3	NA	NA	
ACID PILE	D&M	TP-7	-/BULK	2.0	2.0	2.00	SM	Tails-snd	NA	8.4	2.71	100.0	42.3	NP	NP	109.0	14.5	Triax-CUPP, Consol, Perm, Mod Proct, CMR
ACID PILE	D&M	TP-7	2/ST	5.0	5.5	5.25	CL	Tails-slm	62.5	62.8	NA	NA	NA	NA	NA	NA	NA	Unconf Shear
ACID PILE	D&M	TP-7	3/ST	6.5	7.0	6.75	CL	Tails-slm	64.1	54.4	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	TP-7	4/ST	9.5	10.0	9.75	CL	Tails-slm	51.3	65.0	NA	NA	NA	NA	NA	NA	NA	Unconf Shear
ACID PILE	D&M	TP-7	5/ST	12.5	13.0	12.75	CL	Tails-slm	53.1	74.1	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	TP-7	6/ST	16.5	17.0	16.75	CL	Tails-slm	51.4	55.1	NA	NA	NA	NA	NA	NA	NA	Unconf Shear
ACID PILE	D&M	TP-8	1/ST	2.5	3.0	2.75	SM/ML	Tails-snd/slm	78.5	11.8	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	TP-8	2/ST	4.5	5.0	4.75	SM	Tails-snd	90.6	8.5	2.82	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	TP-8	-/BULK	4.5	4.5	4.50	SM	Tails-snd	NA	7.6	NA	100.0	28.9	NA	NA	103.8	15.8	Dir Shear, Perm, Mod Proct, CMR
ACID PILE	D&M	TP-8	3/ST	6.0	6.5	6.25	SM	Tails-snd(?)	82.5	14.3	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	TP-8	4/ST	10.0	10.5	10.25	ML	Tails-slm	85.7	30.6	2.76	100.0	63.5	NA	NA	NA	NA	
ACID PILE	D&M	TP-8	5/ST	12.0	12.5	12.25	CL	Tails-slm	59.2	70.9	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	TP-8	-/BULK	13.0	13.0	13.00	CL	Tails-slm	NA	NA	NA	NA	NA	NA	NA	NA	NA	Perm

/20

TJO 6/94

17/20

MRAP - 710002307 - GEOTECHNICAL DATA BASE FOR MONTICELLO MILLSITE CHARACTERIZ...ION -- R.N. MORRIS: CREATED 09/30/91: LAST UPDATED 11/22/91

AREA	DATA SOURC	BORING OR TEST PIT NUMBER	SAMPLE NUMBER & TYPE	TOP OF SAMPLE (FEET)	BASE OF SAMPLE (FEET)	SAMPLE MIDPOINT (FEET)	USCS SYMBOL	MATERIAL TYPE	IN-PLACE DRY DENSITY (PCF)	NATURAL MOISTURE CONTENT (PERCENT)	SPECIFIC GRAVITY	FRACTION PASSING #4 SIEVE (PERCENT)	FRACTION PASSING #200 SIEVE (PERCENT)	LIQUID LIMIT	PLASTICITY INDEX	ASTM D 698 MAXIMUM DRY DENSITY (PCF)	ASTM D 698 OPTIMUM MOISTURE CONTENT (PERCENT)	OTHER TESTS
ACID PILE	D&M	TP-8	1/ST	1.5	2.0	1.75	SM	Tailsand	89.4	4.6	NA	NA	NA	NA	NA	NA	NA	
ACID PILE	D&M	TP-8	2/ST	3.0	3.5	3.25	SM	Tailsand	86.0	8.6	NA	100.0	18.8	NA	NA	NA	NA	
ACID PILE	D&M	TP-6	-/BULK	10.0	10.0	10.00	ML	Alluvium	NA	23.4	NA	93.5	89.0	34.2	18.1	114.0	14.9	Perm, Med Prod, CMR
SOMERVILLE TRACT	BENDIX	MRAP-85-17	MKB-786/SS	0.0	2.0	1.00	SC	Alluvium	NA	48.2	2.83	100.0	31.0	33.0	10.0	NA	NA	Perm, CMR @15 bar
SOMERVILLE TRACT	BENDIX	MRAP-85-17	MKB-800/BULK	0.0	5.0	2.50	ML	Alluvium(Shale?)	NA	NA	NA	87.0	81.8	NA	NA	106.3	17.0	
SOMERVILLE TRACT	BENDIX	MRAP-85-18	MKB-788/SS	0.0	2.0	1.00	CL	Alluvium	NA	14.3	2.55	100.0	95.0	32.0	14.0	NA	NA	Perm, Consol w/perm, CMR @15 bar
SOMERVILLE TRACT	BENDIX	MRAP-85-18	MKB-833/BULK	0.0	5.0	2.50	ML	Alluvium	NA	NA	NA	100.0	80.0	NA	NA	103.3	18.0	
BLM COMPOUND	BENDIX	MRAP-85-20	MKB-783/SS	0.0	2.0	1.00	OL	Alluvium	NA	16.5	2.62	100.0	80.0	41.0	7.0	NA	NA	Perm, CMR @15 bar
BLM COMPOUND	BENDIX	MRAP-85-20	MKB-838/BULK	0.0	3.0	1.50	OL	Alluvium	NA	NA	NA	100.0	71.8	NA	NA	101.9	18.8	
BLM COMPOUND	D&M	365E81-058	2/SS	3.5	4.5	4.00	CL	Alluvium	NA	25.4	NA	NA	NA	40.7	20.0	NA	NA	
BLM COMPOUND	D&M	365E81-058	3B/SS	4.5	5.5	5.00	CL	Alluvium	NA	31.8	NA	NA	NA	36.0	15.8	NA	NA	
BLM COMPOUND	D&M	365E81-068	4B/SS	9.0	10.5	9.75	ML	Alluvium	NA	27.1	NA	100.0	79.2	NA	NA	NA	NA	
VALLEY BOTTOM	BENDIX	MRAP-85-21	MKB-756/SS	0.0	2.0	1.00	OL	Alluvium	NA	7.3	2.80	NA	NA	30.0	10.0	NA	NA	Perm, CMR @15 bar
VALLEY BOTTOM	BENDIX	MRAP-85-21	MKB-828/BULK	0.0	3.0	1.50	SM	Tailsand	NA	NA	NA	100.0	43.0	NA	NA	115.2	12.6	
VALLEY BOTTOM	D&M	31SW81-001	3/SS	3.5	4.8	4.15	CL	Alluvium	NA	12.8	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	31SW81-001	7/SS	8.5	10.0	9.25	CL	Alluvium	NA	15.8	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	31SW81-001	8/SS	13.5	14.3	13.90	CL	Alluvium	NA	15.3	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	31SW81-001	11/BULK	24.0	25.0	24.50	GC	Alluvium	NA	16.5	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	31SW81-023	2/SS	8.5	9.0	8.75	SC	Alluvium	NA	9.9	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	31SW81-023	3/SS	13.5	13.8	13.65	SW	Alluvium	NA	6.4	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	31SW81-030	1/SS	4.0	6.0	5.00	CL	Alluvium	NA	16.9	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	31SW81-030	2/SS	9.5	11.0	10.25	SC	Alluvium	NA	12.5	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	31SW81-030	3/SS	14.3	14.7	14.50	Km	Shale	NA	12.3	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	365E81-071	1/SS	3.5	4.0	3.75	SM	Alluvium	NA	10.2	NA	83.1	46.7	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	365E81-071	4/SS	9.5	10.0	9.75	SP	Alluvium	NA	8.1	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	365E81-071	6/SS	14.0	14.5	14.25	SM	Alluvium	NA	13.8	NA	80.4	18.5	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	365E81-072	1/SS	4.5	5.0	4.75	ML	Alluvium	NA	10.7	NA	97.3	71.3	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	365E81-084a	3/SS	8.0	8.5	8.25	ML	Alluvium(?)	NA	8.8	NA	100.0	51.4	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	365E81-084a	4/SS	10.0	10.5	10.25	ML	Alluvium(?)	NA	8.9	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	365E81-084a	5/SS	13.5	14.5	14.00	CL	Alluvium(?)	NA	12.2	NA	NA	NA	NA	NA	NA	NA	
VALLEY BOTTOM	D&M	TP-13	-/BULK	5.0	5.0	5.00	GC	Alluvium	NA	20.2	NA	68.1	41.8	38.4	17.8	116.1	13.2	
MAIN MILLSITE	D&M	31SW81-068b	8/SS	6.0	6.5	6.25	CL	Alluvium	NA	27.7	NA	NA	NA	NA	NA	NA	NA	
MAIN MILLSITE	D&M	31SW81-068b	9A/SS	9.3	9.6	9.45	CL	Alluvium	NA	28.6	NA	NA	NA	NA	NA	NA	NA	
MAIN MILLSITE	D&M	31SW81-068b	10/SS	13.5	15.0	14.25	CL	Alluvium	NA	31.5	NA	NA	NA	NA	NA	NA	NA	
MAIN MILLSITE	D&M	365E81-081	2/SS	3.5	4.5	4.15	CL	Alluvium(Shale?)	NA	23.9	NA	NA	NA	NA	NA	NA	NA	
MAIN MILLSITE	D&M	365E81-087a	18/SS	0.5	2.0	1.25	CL	Fill	NA	11.8	NA	NA	NA	48.3	22.9	NA	NA	
SOUTH VALLEY WALL	D&M	31SW81-011	3/SS	10.0	10.5	10.25	CL	Alluvium(Shale?)	NA	23.8	NA	NA	NA	NA	NA	NA	NA	
SOUTH VALLEY WALL	D&M	31SW81-021	4/SS	8.5	9.0	8.75	CL	Alluvium	NA	7.3	NA	NA	NA	NA	NA	NA	NA	
SOUTH VALLEY WALL	D&M	31SW81-022	4/SS	10.0	10.5	10.25	CL	Alluvium	NA	10.8	NA	NA	NA	NA	NA	NA	NA	
SOUTH VALLEY WALL	D&M	31SW81-034	1/SS	2.0	2.5	2.25	CL	Alluvium	NA	8.8	NA	NA	NA	NA	NA	NA	NA	
SOUTH VALLEY WALL	D&M	31SW81-034	3/SS	9.6	10.3	9.96	CL	Alluvium	NA	14.2	NA	NA	NA	NA	NA	NA	NA	
SOUTH VALLEY WALL	D&M	31SW81-034	4/SS	10.3	11.6	10.95	SC	Alluvium	NA	14.6	NA	NA	NA	NA	NA	NA	NA	
SOUTH VALLEY WALL	D&M	31SW81-034	5/SS	14.0	14.2	14.10	CL	Alluvium	NA	12.2	NA	NA	NA	NA	NA	NA	NA	
SOUTH VALLEY WALL	D&M	31SW81-054	4/SS	4.5	5.0	4.75	CL	Alluvium	NA	11.4	NA	100.0	80.4	43.3	22.4	NA	NA	
NORTH VALLEY WALL	D&M	31SW81-016	1B/SS	3.5	5.5	4.50	CL	Alluvium(?)	NA	12.9	NA	NA	NA	38.2	17.1	NA	NA	
NORTH VALLEY WALL	D&M	31SW81-016	2B/SS	8.5	10.5	9.50	CL	Alluvium(?)	NA	20.1	NA	100.0	97.8	NA	NA	NA	NA	
NORTH VALLEY WALL	D&M	31SW81-033	1/SS	2.0	4.0	3.00	CL	Alluvium	NA	14.2	NA	NA	NA	NA	NA	NA	NA	
NORTH VALLEY WALL	D&M	31SW81-033	3/SS	9.0	11.0	10.00	CL	Alluvium	NA	10.8	NA	NA	NA	33.4	13.8	NA	NA	
NORTH VALLEY WALL	D&M	31SW81-063	3B/SS	8.5	9.0	8.75	CL	Alluvium(?)	NA	21.2	NA	NA	NA	NA	NA	NA	NA	
NORTH VALLEY WALL	D&M	31SW81-063	6B/SS	14.5	15.0	14.75	CL	Alluvium(?)	NA	23.8	2.70	NA	NA	48.3	23.0	NA	NA	
NORTH VALLEY WALL	D&M	31SW81-063	7B/SS	18.5	19.0	18.75	CL	Alluvium(?)	NA	23.8	NA	NA	NA	NA	NA	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-073	1/SS	3.5	3.8	3.65	CL	Alluvium	NA	11.9	NA	NA	NA	38.1	15.9	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-073	3/SS	13.5	14.3	13.90	CL	Alluvium	NA	13.8	NA	NA	NA	NA	NA	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-073	4/SS	20.0	20.5	20.25	CL	Alluvium	NA	30.1	NA	NA	NA	44.8	22.8	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-076	3/SS	5.0	5.5	5.25	CL	Alluvium	NA	23.9	NA	NA	NA	41.3	20.7	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-076	4/SS	9.5	10.0	9.75	CL	Alluvium	NA	17.5	NA	NA	NA	NA	NA	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-076	6/SS	15.0	15.5	15.25	CL	Alluvium	NA	16.8	NA	NA	NA	27.0	8.4	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-076	7/SS	20.0	20.5	20.25	CL	Alluvium	NA	19.1	NA	NA	NA	NA	NA	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-077	2/SS	3.5	4.3	3.90	CL	Alluvium(Loess?)	NA	17.4	NA	NA	NA	49.8	22.7	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-077	3/SS	8.5	9.5	9.00	CL	Alluvium(Loess?)	NA	15.6	NA	NA	NA	NA	NA	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-078	2/SS	8.5	9.5	9.00	CL	Alluvium	NA	18.0	NA	NA	NA	NA	NA	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-078	3/SS	13.5	14.3	13.90	CL	Alluvium	NA	16.8	NA	NA	NA	NA	NA	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-080	2/SS	5.0	6.0	5.50	CL	Alluvium	NA	15.9	NA	NA	NA	44.7	22.4	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-080	3/SS	10.0	10.8	10.40	SW	Alluvium	NA	6.9	NA	NA	NA	NA	NA	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-082	2/SS	3.5	4.0	3.75	SM	Alluvium	NA	6.9	NA	86.9	38.4	NA	NA	NA	NA	
BLM PROPERTY-NORT	D&M	365E81-082	3/SS	8.5	10.5	9.50	CL	Alluvium(?)	NA	23.5	NA	NA	NA	NA	NA	NA	NA	

TKS
0/6/94

UMTRA - 710002307 - GEOTECHNICAL DATABASE FOR MONTICELLO MILLSITE CHARACTERIZATION -- R.N. MORRIS: CREATED 09/30/91: LAST UPDATED 11/22/91

AREA	DATA SOURC	BORING OR TEST PIT NUMBER	SAMPLE NUMBER & TYPE	TOP OF SAMPLE (FEET)	BASE OF SAMPLE (FEET)	SAMPLE MIDPOINT (FEET)	USCS SYMBOL	MATERIAL TYPE	IN-PLACE DRY DENSITY (PCF)	NATURAL MOISTURE CONTENT (PERCENT)	SPECIFIC GRAVITY	FRACTION PASSING #4 SIEVE (PERCENT)	FRACTION PASSING #200 SIEVE (PERCENT)	LIQUID LIMIT	PLASTICITY INDEX	ASTM D 698 MAXIMUM DRY DENSITY (PCF)	ASTM D 698 OPTIMUM MOISTURE CONTENT (PERCENT)	OTHER TESTS
BLM PROPERTY-NORT	D&M	TP-10	*BULK	5.0	5.0	5.00	CL	Loess[?]	NA	10.9	NA	100.0	88.8	29.5	11.1	107.7	14.2	Mod Proct
BLM PROPERTY-NORT	D&M	TP-10	2ST	4.0	6.5	5.25	CL	Loess[?]	91.7	8.2	NA	NA	NA	27.9	9.8	NA	NA	Unconf Comp
BLM PROPERTY-NORT	D&M	TP-10	4ST	11.0	11.5	11.25	CL	Loess[?]	109.3	10.7	NA	NA	NA	43.8	21.8	NA	NA	Perm

KEY:

USCS United Soil Classification System group symbol, ASTM D 2487 or D2488 (For rocks, symbol indicates geologic unit)
ASTM Test designation of the American Society for Testing and Materials
BENDIX "Data Collection for Engineering for the Uranium Mill Tailings Site and Adjacent Peripheral Properties, Monticello, Utah," Bendix Field Engineering Corporation, September 1986
D&M "Final Report, Monticello Remedial Action Project, 1991 Millsite Characterization Study," Dames & Moore, September 17, 1991
* Sample taken from a test pit excavated next to the designated borehole.
[?] Questionable value or identification

MATERIAL TYPE:

- Tails-snd — Tailings sands
- Tails-slm — Tailings slimes
- Tails-snd/slm — Tailings sands and slimes, interbedded
- Tails-snd&slm — Tailings sands and slimes, mixed
- Cover — Cover material in place on tailings piles
- MVP spoils — Material removed from Monticello Vicinity Properties
- Alluvium — Miscellaneous surficial deposits, mostly stream-laid
- Loess — Windblown fine-grained deposits
- Shale — Mancos Shale, usually weathered
- Sandstone — Dakota Sandstone
- Fill — Miscellaneous man-made fill

OTHER TESTS:

- Mod Proct — Modified Proctor compaction
- Unconf Comp — Unconfined compressive strength
- Dir Shear — Direct shear, consolidated-drained
- Triax-CUPP — Triaxial shear, consolidated-undrained with pore pressure measurements
- Consol — One-dimensional consolidation
- Perm — Permeability, falling-head or flexible-membrane
- CMR — Capillary moisture rise

SAMPLE TYPES:

- BULK — Disturbed bag sample of loose cuttings or material from test pit
- SS — Disturbed sample from 3.0" O.D. standard split-spoon drive sampler
- ST — Relatively undisturbed sample from 3.0" O.D. thin-walled (Shelby) tube sampler
- U — Relatively undisturbed sample from Dames & Moore Type "U" ring-lined drive sampler

All data in this table compiled or interpreted from consultant's reports by R.N. Morris, Chem-Nuclear Geotech, Inc., October 1991. Checked by L.H. Ogden & corrected by R.N. Morris, November 1991.

7/20

APPENDIX B

Radon Calculation

Purpose: To determine the required soil cover thicknesses to limit radon emissions from the White Mesa tailings impoundments to 20 pCi/m^2/sec using United States Nuclear Regulatory Commission (NRC) approved methods and inputs. The White Mesa Mill site is located in Blanding, Utah.

Method: Determine the geotechnical and radiological properties of the tailings and cover materials based on NRC-accepted methods and existing database values previously collected. Input parameters into the computer modeling program "RADON" to determine the radon flux values through the cover materials. A variety of scenarios adjusting cover thicknesses were run to determine the optimum thickness of cover materials to meet NRC specifications. It was assumed that the tailings located in the three cells at the White Mesa Mill site (Cells 2, 3, and 4A) have similar properties (Figure 1). Therefore, cover layer configurations as determined by the RADON model are applicable to the three tailings cells.

Results: A 2-layer uranium mill tailings cover composed of (from top to bottom) a 2-foot layer of random fill and a 1-foot compacted clay layer will meet NRC specifications. In addition to the tailings cover materials, a minimum of 3 feet of random fill will be placed between the tailings and soil cover to fill the currently existing freeboard. This 3 foot layer was included for modeling purposes since it will assist in reducing the radon flux from the tailings impoundments. This layer, however, is not considered a part of the actual soil cover. The resulting radon flux exiting the top cover layer of the tailings impoundment will be 13.6 pCi/m^2/sec (see Appendix A1 for RADON output).

As indicated in the "Effects of Freezing on Uranium Mill Tailings Covers Calculation Brief" (6/17/96), 6.8 inches of the top random fill cover layer will be effected by freeze/thaw conditions at Blanding Utah. This suggests that 6.8 inches of the top layer may not contribute to reductions of radon emanation from the tailings covers. To conservatively compensate for effects from freezing and thawing, 6.8 inches were subtracted from the top random fill cover layer. Executing the RADON model based on this cover configuration resulted in a radon flux emanation of 17.6 pCi/m^2/sec (see Appendix A2 for RADON output).

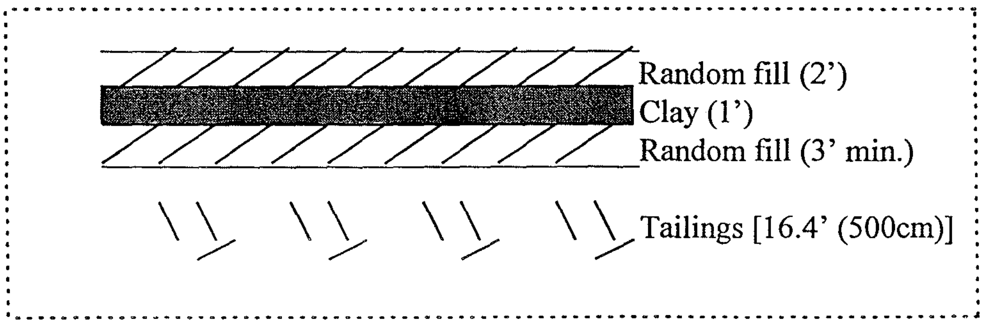
NRC specifications (Regulatory Guide 3.64) requires that a uranium tailings cover "..produce resonable assurance that the radon-222 release rate would not exceed 20 pCi/m^2/sec for a period of 1,000 years to the extent reasonably achievable and in any case for at least 200 years when averaged over the disposal area over at least a one-year period" (NRC, 1989). Therefore, the above design with accounting for freezing and thawing conditions is adequate.

Parameters: The RADON model requires input of the following parameters for all tailings and soil cover layers:

- layer thickness (centimeter (cm));
- porosity;
- mass density (g/cm^3);
- radium activity (pCi/gr), source term, or ore grade percentage;
- emanation coefficient;
- weight percent moisture (long-term) (percent), and;
- diffusion coefficient (cm^2/sec).

Physical and radiological properties for Tailings and Random Fill were analyzed by Chen and Associates (1987) and Rogers and Associates (1988) respectively. See Appendix B1 for analysis results. Clay physical data input for RADON modeling are included in Appendix B2 and were analyzed by Advanced Terra Testing (1996) and Rogers and Associates (1996).

The following cover profile was modeled.



This cover configuration represents the actual cover layer thicknesses which would be constructed on site. The cover profile above was adjusting for modeling purposes to account for freezing and thawing conditions. The modeled profile is identical to the one above with the exception of the top random fill layer which was reduced to 1.4 feet (2 feet minus 6.8 inches). It is assumed that 6.8 inches of the top cover layer effected by freeze/thaw conditions will not contribute to reductions in radon emanation from the tailings covers.

Layer thicknesses

The thickness of the tailings was assumed to be effectively an infinitely thick radon source. In accordance with NRC criteria (Reg. Guide 3.64, p. 3.64-5) a tailings thickness greater than about 100-200 cm is considered to be effectively, infinitely thick. A value of 500 cm represents an equivalent infinitely thick tailings source. The actual tailings thickness of Cell 3 at White Mesa is approximately 28 feet (850 cm), therefore, a value of 500 cm was used for the RADON model.

A minimum of 3-feet (91.5 cm) of random fill will cover the tailings to fill the existing freeboard and bring the tailings piles up to the subgrade elevation of the soil cover. A 1-foot (30.5 cm) layer of compacted clay covers the random fill with an additional 2 feet (61 cm) of random fill overlying the clay layer. Adjusting for freeze/thaw conditions results in a (43 cm) random fill layer overlaying the clay layer.

Porosity

Porosity is calculated from the specific gravity and dry bulk density according to the following equations;

1. Dry bulk density = [(specific gravity)(density of water)]/[1 + e] (Ref.: Principles & Practice of Civil Engineering, 1996, equation 14.5.6). See Appendix C.
2. Porosity = [e / (1+e)] x 100 (Ref.: Principles & Practice of Civil Engineering, 1996, equation 14.5.4). See Appendix C.

	Max. Dry Density (lb/ft^3)	Bulk Dry Density (lb/ft^3) (1)	Specific Gravity	Density of Water (lb/ft^3)	"e" (2)	**porosity (3)**
Tailings (4)	104.0	98.8	2.85	62.4	0.80	**44%**
Clay (5)	113.5	107.8	2.39	62.4	0.38	**28%**
Random fill (4)	120.2	114.2	2.67	62.4	0.46	**31.5%**

Notes:

1. Bulk dry density is 95% of the ASTM Proctor maximum dry density for all materials.
2. Calculated using Equation 1 above where "e" is the volume of voids per volume of solids.
3. Calculated using Equation 2 above.
4. Physical tailings and random fill data from Chen and Associates (1987) included in Appendix B1.
5. Clay physical data from Advanced Terra Testing (1996) and Rogers and Associates (1996) included in Appendix B2.

Mass Density

Mass densities were measured by Rogers and Associates (1988 and 1996) to be (see Appendix B1 and B2):

Tailings	=	1.45 g/cm^3
Clay	=	1.72 g/cm^3
Random Fill	=	1.85 g/cm^3

Radium Activity, Source Term, or Ore Grade %

Radium activity values from Rogers & Associates (1988 and 1996), were input for White Mesa tailings and cover materials (Appendix B1 and B2). The radium activity values are:

Tailings	=	981 pCi/gm
Clay	=	1.5 pCi/gm
Random Fill	=	1.9 pCi/gm.

Emanation Coefficient

Emanation coefficient input for the tailings and cover materials are measured values from Rogers & Associates (1988 and 1996), included in Appendix B1 and B2. The coefficients are:

Tailings	=	0.19
Clay	=	0.22
Random Fill	=	0.19

Note: Use of NRC's default value of E=0.35 is not considered appropriate since laboratory analyses of emanation coefficients are available.

Weight Percent Moisture

Long-term moisture content (weight percent moisture) was assumed to be 6% for the tailings. NRC Regulatory Guide 3.64 states, "if acceptable documented alternative information is not furnished by the applicant, the staff will use a reference value of 6% for the tailings moisture content because 6% is a lower bound for moisture in western soils" (NRC, 1989). Laboratory data does not exist to determine the actual weight percent moisture of tailings therefore, this is a conservative assumption.

The weight percent moisture of the new clay source (UT-1) is also unknown therefore, it was assumed that the average weight percent moisture from clay (site #1 and site #4) would be equivalent to the new clay source (UT-1). This is also a conservative assumption as the new clay source is believed to be of better quality. Weight percent moisture values for clay and random fill were derived from the "Summary of Capillary Moisture Relationship Test Results" figures included in Appendix B1. Weight percent moisture values used for modeling purposes are:

Tailings	= 6%
Clay	= 14.1%
Random Fill	= 9.8%

Diffusion Coefficient

Diffusion coefficient input for the tailings and cover materials are measured values from Rogers & Associates (1988 and 1996), included in Appendix B1 and B2. The coefficients used for tailings and random fill were an average of the two values presented. The coefficients for each material are as follows:

Tailings	= 0.0142 cm^2/sec
Clay	= 0.0091 cm^2/sec
Random Fill	= 0.0082 cm^2/sec

References:

Advanced Terra Testing, 1996, Physical soil data, White Mesa Project, Blanding Utah, July 25, 1996.

Chen and Associates, 1987. Physical soil data, White Mesa Project Blanding Utah.

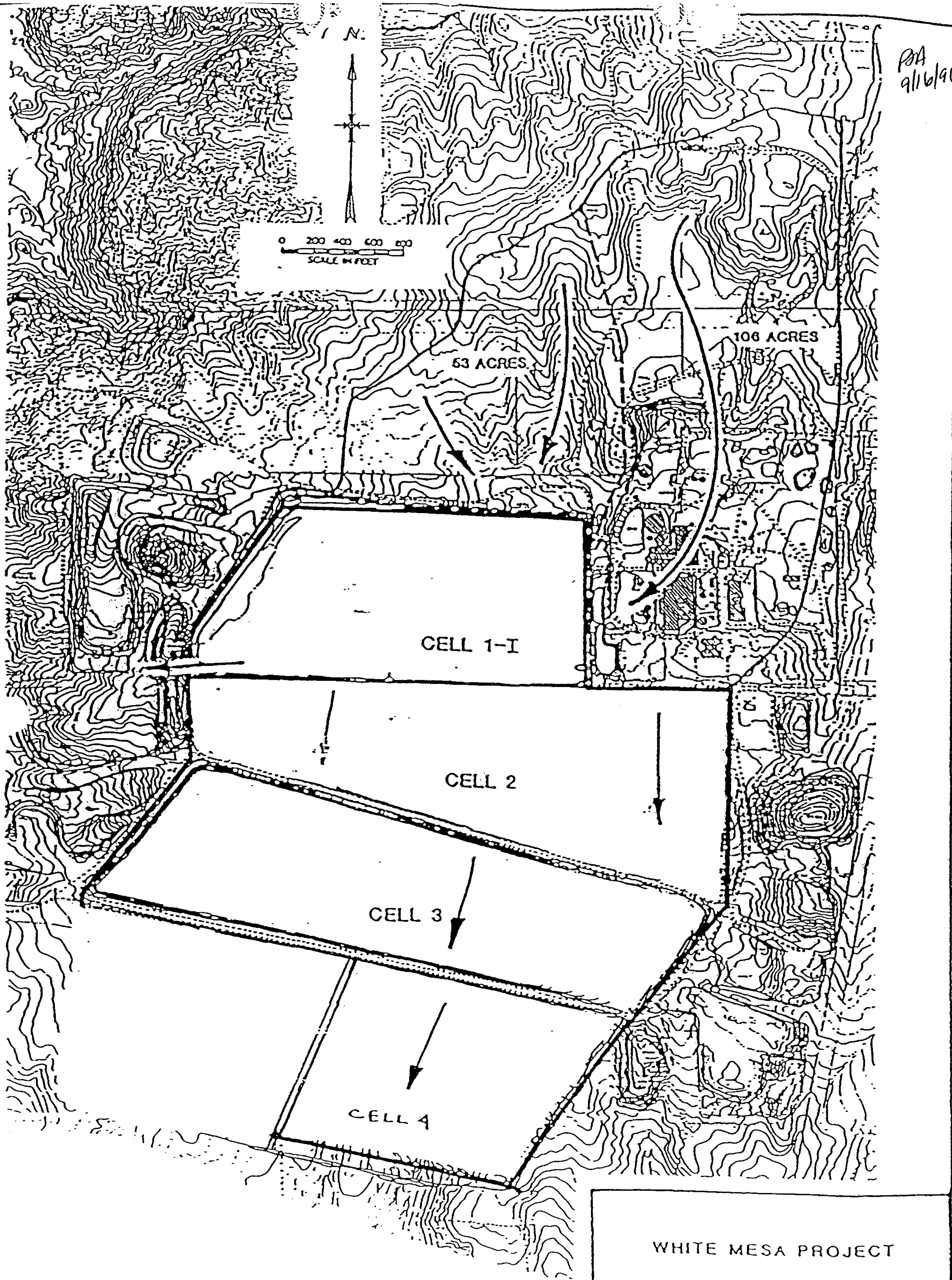
Freeze R. Allan and Cherry, John A., 1979, "Groundwater".

Principles & Practice of Civil Engineering, 2nd Edition, 1996.

Rogers and Associates Engineering Company, 1988. Radiological Properties Letters to C.O. Sealy from R.Y. Bowser dated March 4 and May 9, 1988.

Rogers and Associates Engineering Company, 1996. Report of Radon Diffusion Coefficient Measurements, Radium Content, and Emanation Coefficient Measurements, September 3, 1996.

U.S. Nuclear Regulatory Commission (NRC), 1989. "Regulatory Guide 3.64 (Task WM 503-4) Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers", March 1989.



WHITE MESA PROJECT

SITE DRAINAGE

FIGURE: 1

Appendix A1

-----*****! RADON !*****-----

Version 1.2 - MAY 22, 1989 - G.F. Birchard tel.# (301)492-7000
U.S. Nuclear Regulatory Commission Office of Research

RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS

DATE/TIME OF THIS RUN
09-10-1996/18:06:33

EFN - WHITE MESA

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	4	
DESIRED RADON FLUX LIMIT	20	pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 TAILINGS

THICKNESS	500	cm
POROSITY	.44	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	981	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.19	
CALCULATED SOURCE TERM CONCENTRATION	1.290D-03	pCi cm^-3 s^-1
WEIGHT % MOISTURE	6	%
MOISTURE SATURATION FRACTION	.198	
MEASURED DIFFUSION COEFFICIENT	.0142	cm^2 s^-1

LAYER 2 RANDOM FILL (FILL FREEBOARD)

THICKNESS	91.5	cm
POROSITY	.315	
MEASURED MASS DENSITY	1.85	g cm^-3
MEASURED RADIUM ACTIVITY	1.9	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.19	
CALCULATED SOURCE TERM CONCENTRATION	4.452D-06	pCi cm^-3 s^-1
WEIGHT % MOISTURE	9.800000000000001	%
MOISTURE SATURATION FRACTION	.576	
MEASURED DIFFUSION COEFFICIENT	8.200000000000001D-03	cm^2 s^-1

LAYER 3 CLAY (UT-1)

THICKNESS	30.5	cm
ROSITY	.28	
MEASURED MASS DENSITY	1.72	g cm^-3
MEASURED RADIUM ACTIVITY	1.5	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.22	
CALCULATED SOURCE TERM CONCENTRATION	4.257D-06	pCi cm^-3 s^-1
WEIGHT % MOISTURE	14.1	%
MOISTURE SATURATION FRACTION	.866	
MEASURED DIFFUSION COEFFICIENT	.0091	cm^2 s^-1

LAYER 4 RANDOM FILL

THICKNESS	61	cm
POROSITY	.315	
MEASURED MASS DENSITY	1.85	g cm^-3
MEASURED RADIUM ACTIVITY	1.9	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.19	
CALCULATED SOURCE TERM CONCENTRATION	4.452D-06	pCi cm^-3 s^-1
WEIGHT % MOISTURE	9.800000000000001	%
MOISTURE SATURATION FRACTION	.576	
MEASURED DIFFUSION COEFFICIENT	8.200000000000001D-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DEFAULT DRIVE

N	F01	CN1	ICOST	CRITJ	ACC
4	0.000D+00	0.000D+00	0	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	1.420D-02	4.400D-01	1.290D-03	1.977D-01	1.450
2	9.150D+01	8.200D-03	3.150D-01	4.452D-06	5.756D-01	1.850
3	3.050D+01	9.100D-03	2.800D-01	4.257D-06	8.661D-01	1.720
4	6.100D+01	8.200D-03	3.150D-01	4.452D-06	5.756D-01	1.850

BARE SOURCE FLUX FROM LAYER 1: 4.667D+02 pCi m^-2 s^-1

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	1.233D+02	4.519D+05
2	9.150D+01	2.562D+01	7.892D+04
3	3.050D+01	1.962D+01	2.276D+04
4	6.100D+01	1.361D+01	0.000D+00

Appendix A2

-----*****! RADON !*****-----

Version 1.2 - MAY 22, 1989 - G.F. Birchard tel.# (301)492-7000
U.S. Nuclear Regulatory Commission Office of Research

12/32

RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS

DATE/TIME OF THIS RUN
09-10-1996/14:46:46

EFN - WHITE MESA (ACCOUNTING FOR FREEZE/THAW CONDITIONS)

CONSTANTS

RADON DECAY CONSTANT	.0000021	s^-1
RADON WATER/AIR PARTITION COEFFICIENT	.26	
SPECIFIC GRAVITY OF COVER & TAILINGS	2.65	

GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS	4	
DESIRED RADON FLUX LIMIT	20	pCi m^-2 s^-1
LAYER THICKNESS NOT OPTIMIZED		
DEFAULT SURFACE RADON CONCENTRATION	0	pCi l^-1
RADON FLUX INTO LAYER 1	0	pCi m^-2 s^-1
SURFACE FLUX PRECISION	.001	pCi m^-2 s^-1

LAYER INPUT PARAMETERS

LAYER 1 TAILINGS

THICKNESS	500	cm
POROSITY	.44	
MEASURED MASS DENSITY	1.45	g cm^-3
MEASURED RADIUM ACTIVITY	981	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.19	
CALCULATED SOURCE TERM CONCENTRATION	1.290D-03	pCi cm^-3 s^-1
WEIGHT % MOISTURE	6	%
MOISTURE SATURATION FRACTION	.198	
MEASURED DIFFUSION COEFFICIENT	.0142	cm^2 s^-1

LAYER 2 RANDOM FILL

THICKNESS	91.5	cm
POROSITY	.315	
MEASURED MASS DENSITY	1.85	g cm^-3
MEASURED RADIUM ACTIVITY	1.9	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.19	
CALCULATED SOURCE TERM CONCENTRATION	4.452D-06	pCi cm^-3 s^-1
WEIGHT % MOISTURE	9.800000000000001	%
MOISTURE SATURATION FRACTION	.576	
MEASURED DIFFUSION COEFFICIENT	8.200000000000001D-03	cm^2 s^-1

13/32

LAYER 3 CLAY

THICKNESS	30.5	cm
ROSITY	.28	
MEASURED MASS DENSITY	1.72	g cm^-3
MEASURED RADIUM ACTIVITY	1.5	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.22	
CALCULATED SOURCE TERM CONCENTRATION	4.257D-06	pCi cm^-3 s^-1
WEIGHT % MOISTURE	14.1	%
MOISTURE SATURATION FRACTION	.866	
MEASURED DIFFUSION COEFFICIENT	.0091	cm^2 s^-1

LAYER 4 RANDOM FILL

THICKNESS	43	cm
POROSITY	.315	
MEASURED MASS DENSITY	1.85	g cm^-3
MEASURED RADIUM ACTIVITY	1.9	pCi/g^-1
MEASURED EMANATION COEFFICIENT	.19	
CALCULATED SOURCE TERM CONCENTRATION	4.452D-06	pCi cm^-3 s^-1
WEIGHT % MOISTURE	9.800000000000001	%
MOISTURE SATURATION FRACTION	.576	
MEASURED DIFFUSION COEFFICIENT	8.200000000000001D-03	cm^2 s^-1

DATA SENT TO THE FILE 'RNDATA' ON DEFAULT DRIVE

N	F01	CN1	ICOST	CRITJ	ACC
4	0.000D+00	0.000D+00	0	2.000D+01	1.000D-03

LAYER	DX	D	P	Q	XMS	RHO
1	5.000D+02	1.420D-02	4.400D-01	1.290D-03	1.977D-01	1.450
2	9.150D+01	8.200D-03	3.150D-01	4.452D-06	5.756D-01	1.850
3	3.050D+01	9.100D-03	2.800D-01	4.257D-06	8.661D-01	1.720
4	4.300D+01	8.200D-03	3.150D-01	4.452D-06	5.756D-01	1.850

BARE SOURCE FLUX FROM LAYER 1: 4.667D+02 pCi m^-2 s^-1

14/32

RESULTS OF THE RADON DIFFUSION CALCULATIONS

LAYER	THICKNESS (cm)	EXIT FLUX (pCi m^-2 s^-1)	EXIT CONC. (pCi l^-1)
1	5.000D+02	1.237D+02	4.514D+05
2	9.150D+01	2.679D+01	7.622D+04
3	3.050D+01	2.123D+01	1.944D+04
4	4.300D+01	1.756D+01	0.000D+00

Appendix B1

TAILINGS AND RANDOM FILL PROPERTIES

Table 3.4-1

Physical Properties of Tailings

and

Proposed Cover Materials

Material Type	Atterberg Limits LL	Atterberg Limits PI	Specific Gravity	% Passing No. 200 Sieve	Maximum Dry Density (pcf)	Optimum Moisture Content
Tailings	28	6	2.85	46	104.0	18.1
Random Fill	22	7	2.67	48	120.2	11.8
Clay	29	14	2.69	56	121.3	12.1
Clay	36	19	2.75	68	108.7	18.5

Note: Physical Soil Data from Chen and Associates (1987).

R
A
E
Rogers & Associates Engineering Corporation
Post Office Box 330
Salt Lake City, Utah 84110
(801) 263-1600

17/32

March 4, 1988

Mr. C.O.Sealy
Umetco Minerals Corporation
P.O. Box 1029
Grand Junction, CO 81502

C8700/22

Dear Mr. Sealy:

We have completed the tests ordered on the four samples shipped to us. The results are as follows:

Sample	Radium pCi/gm	Emanation Fraction	Diffusion Coeffic.	(g/cm^3) Density	Moisture	Saturation
Tailings	981±4	0.19±0.01	2.0E-02	1.45	13.2	0.39
			8.4E-03	1.44	19.1	0.56
Composite (2,3,&5)			1.6E-02	1.85	6.5	0.40
			4.5E-04	1.84	12.5	0.75
Site #1			1.6E-02	1.85	8.1	0.48
			1.4E-03	1.84	12.6	0.76
Site #4			1.1E-02	1.65	15.4	0.63
			4.2E-04	1.65	19.3	0.80

The samples will be shipped back to you in the next few weeks. If you have any questions regarding the results on the samples please feel free to call.

Sincerely,

Renee Y. Bowser

Renee Y. Bowser
Lab Supervisor

RYB/b

R
A
E
Rogers & Associates Engineering Corporation

Post Office Box 330
Salt Lake City, Utah 84110
(801) 263-1600

18/32

MAY 12 1988

May 9, 1988

Mr. C.O. Sealy
UMETCO Minerals Corporation
P.O. Box 1029
Grand Junction, CO 81502

C8700/22

Dear Mr. Sealy:

The tests for radium content and radon emanation coefficient in the following samples have been completed and the results are as follows:

Sample	Radium (pCi/g)	Radon Emanation Coefficient
Random (2,3 & 5)	1.9 ± 0.1	0.19 ± 0.04
Site 1	2.2 ± 0.1	0.20 ± 0.03
Site 4	2.0 ± 0.1	0.11 ± 0.04

If you have any questions regarding these results please feel free to call Dr. Kirk Nielson or me.

Sincerely,

Renee Y. Bowser
Lab Supervisor

RYB:ms

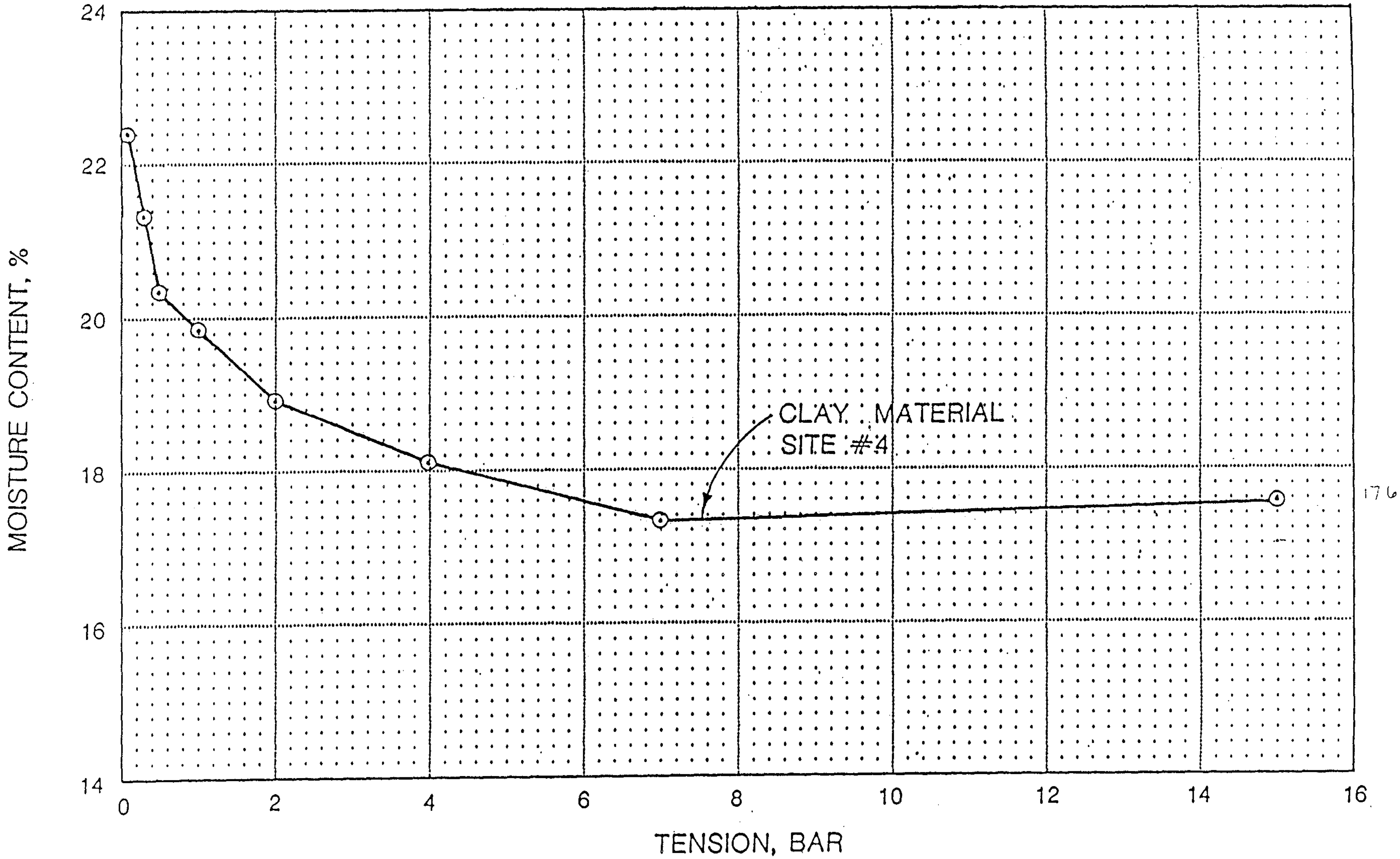


FIGURE 4.4-2

SUMMARY OF CAPILLARY MOISTURE RELATIONSHIP TEST RESULTS

WHITE MESA PROJECT

DATA FROM CHEN & ASSOCIATES;

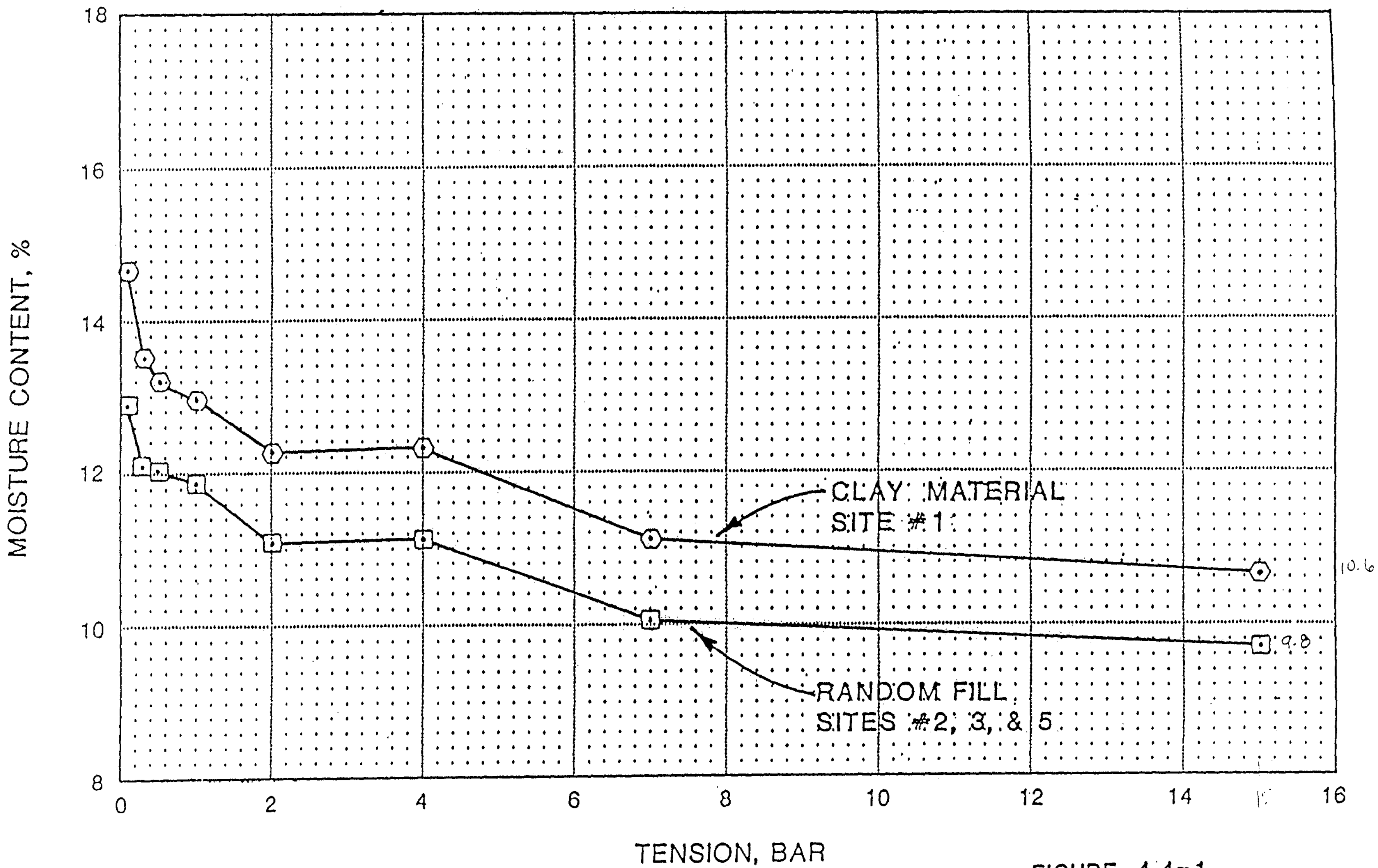


FIGURE 4.4-1

SUMMARY OF CAPILLARY MOISTURE RELATIONSHIP TEST RESULTS

WHITE MESA PROJECT

DATA FROM CHEN & ASSOCIATES

Appendix B2

ADVANCED TERRA TESTING, inc.

833 Parfet Street
Lakewood, Colorado 80215
(303) 232-8308

ATTERBERG LIMITS TEST
ASTM D 4318

CLIENT Titan Env. JOB NO. 2234-04

BORING NO. DATE SAMPLED
DEPTH DATE TESTED 7-25-96 WEB, RV
SAMPLE NO. UT-1
SOIL DESCR.
TEST TYPE ATTERBERG

Plastic Limit
Determination

	1	2	3
Wt Dish & Wet Soil	3.34	4.06	3.42
Wt Dish & Dry Soil	2.96	3.57	3.03
Wt of Moisture	0.38	0.49	0.39
Wt of Dish	1.05	1.11	1.06
Wt of Dry Soil	1.91	2.46	1.97
Moisture Content	19.90	19.92	19.80

Liquid Limit Device Number 0258
Determination

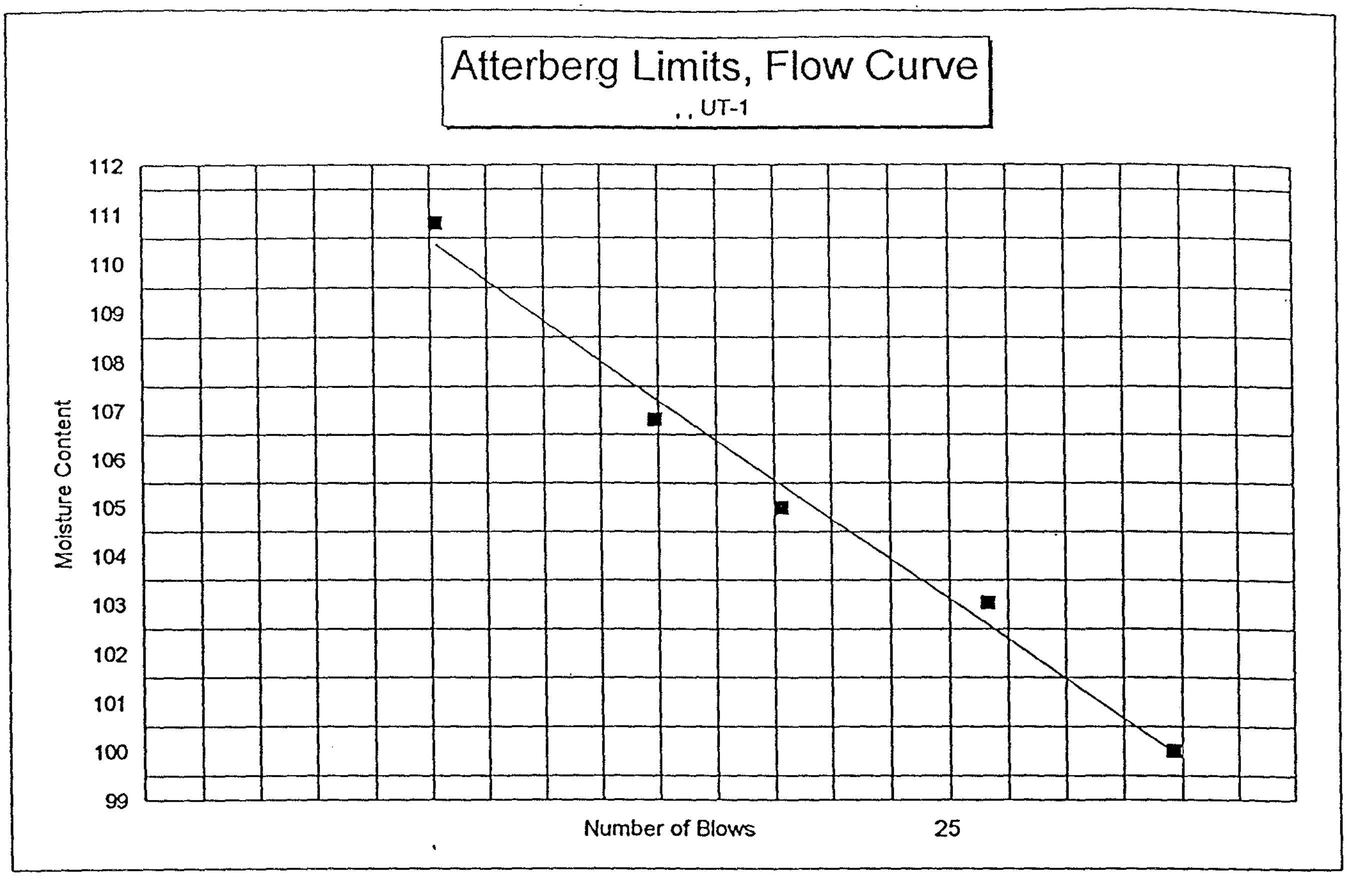
	1	2	3	4	5
Number of Blows	39	27	18	14	9
Wt Dish & Wet Soil	12.18	10.42	10.92	12.33	10.06
Wt Dish & Dry Soil	6.64	5.67	5.87	6.53	5.34
Wt of Moisture	5.54	4.75	5.05	5.80	4.72
Wt of Dish	1.10	1.06	1.06	1.10	1.08
Wt of Dry Soil	5.54	4.61	4.81	5.43	4.26
Moisture Content	100.00	103.04	104.99	106.81	110.80

Liquid Limit 103.1
Plastic Limit 19.9
Plasticity Index 83.3

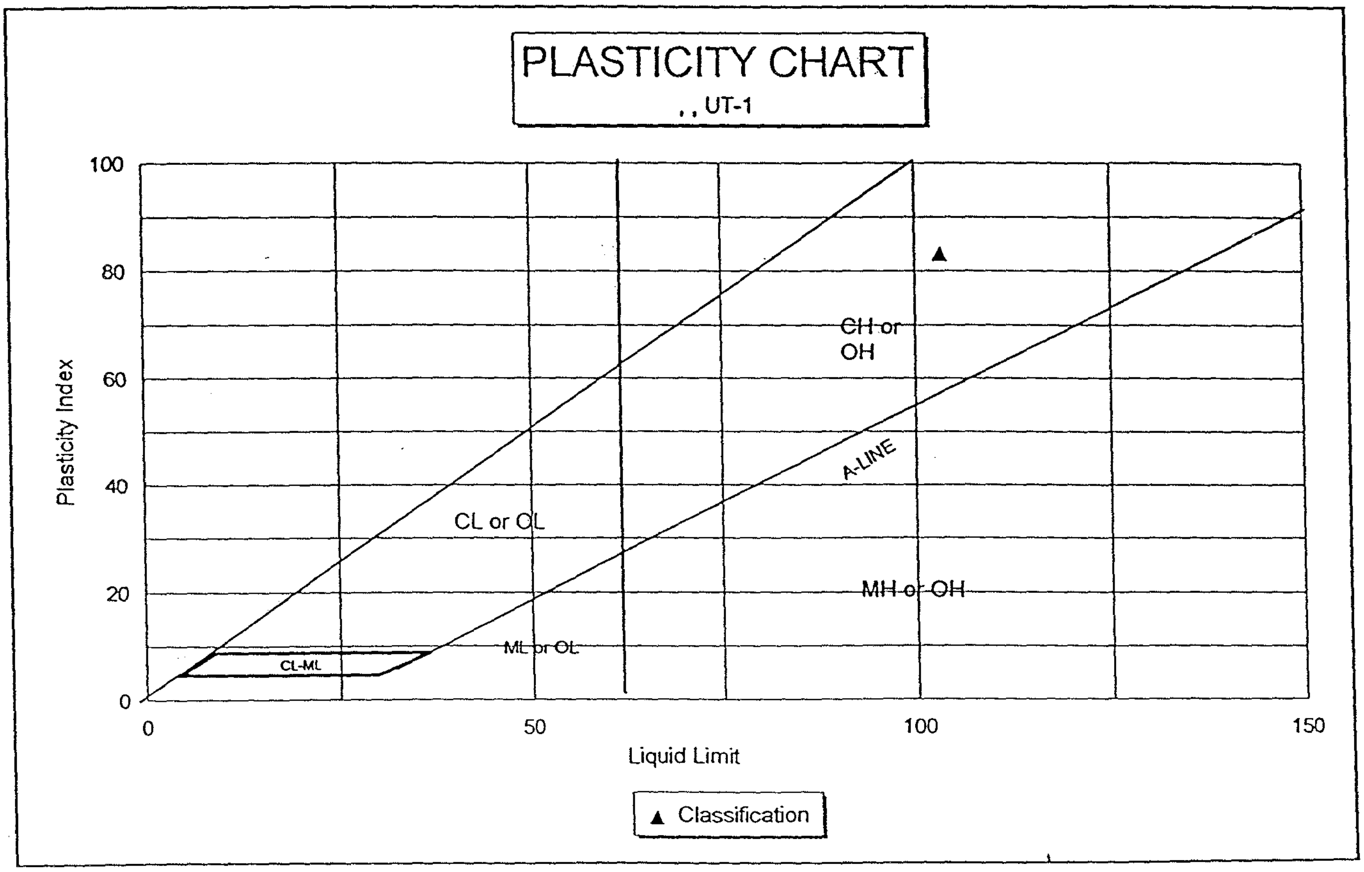
Atterberg Classification CH

Data entry by: NAA Date: 7-26-96
Checked by: [signature] Date: 7-26-96
FileName: TIGOUT1

ADVANCED TERRA TESTING, INC.



Atterberg Limits, Flow Curve
, , UT-1
112
111
110
109
108
107
106
105
104
103
102
101
100
99
Moisture Content
Number of Blows
25



PLASTICITY CHART
, , UT-1
100
80
60
40
20
0
Plasticity Index
CH or
OH
A-LINE
CL or OL
MH or OH
ML or OL
CL-ML
0
50
100
150
Liquid Limit
▲ Classification

C :PACTION TEST
ASTM D 1557 A

CLIENT: TItan Env. JOB NO. 2234-04

25/32

BORING NO. SOIL DESCR.
EPTH DATE SAMPLED
SAMPLE NO. UT-1 DATE TESTED 7-25-96 RV

Moisture determination

	1	2	3	4	5
Wt of Moisture added (ml)	100.00	150.00	250.00	350.00	450.00
Wt. of soil & dish (g)	384.26	393.92	291.42	244.20	281.17
Dry wt. soil & dish (g)	350.60	355.61	251.40	202.69	225.04
Net loss of moisture (g)	33.66	38.31	40.02	41.51	56.13
Wt. of dish (g)	8.01	8.34	8.31	8.29	8.43
Net wt. of dry soil (g)	342.59	347.27	243.09	194.40	216.61
Moisture Content (%)	9.83	11.03	16.46	21.35	25.91
Corrected Moisture Content					

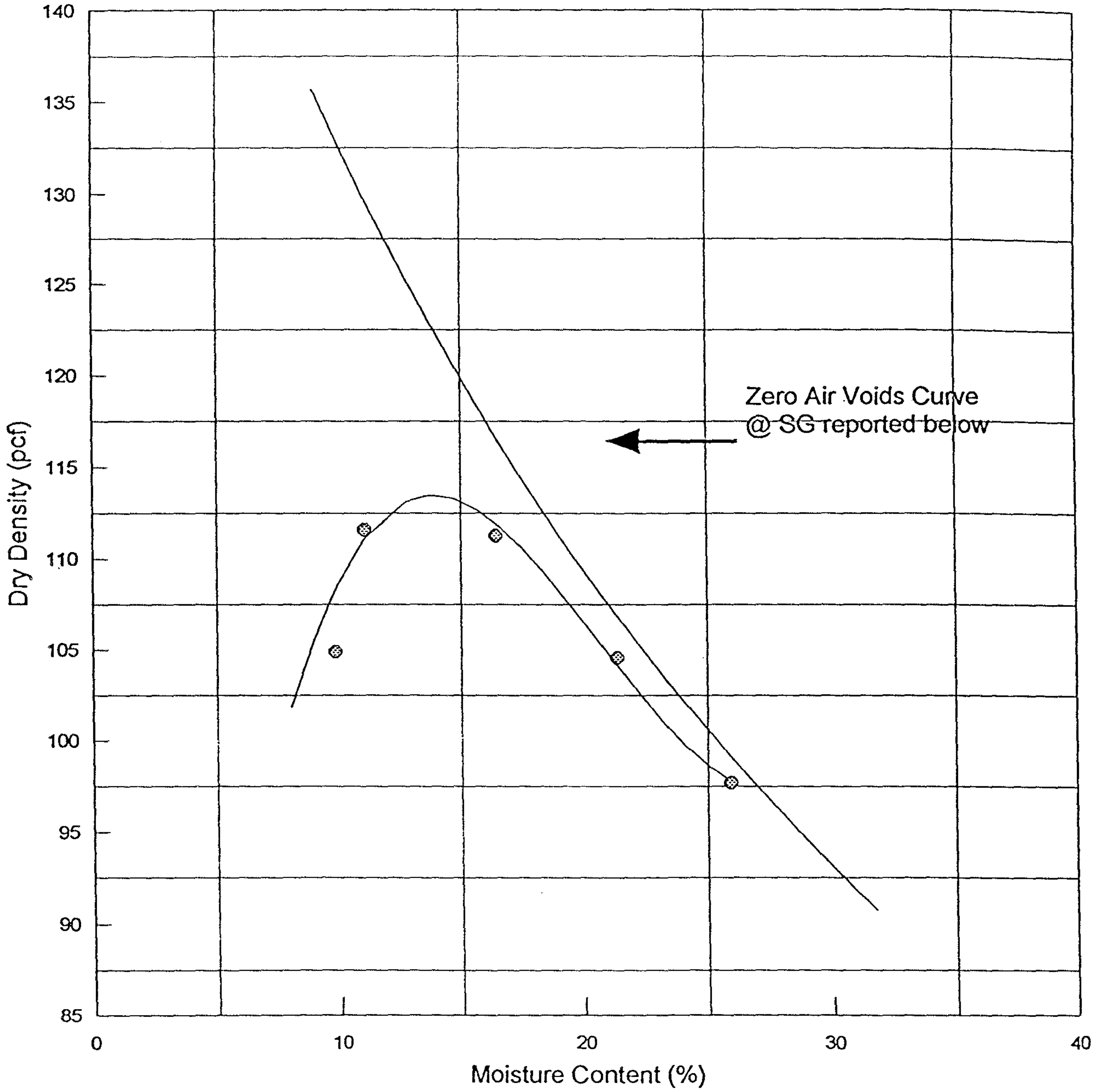
Density determination

Wt of soil & mold (lb)	14.20	14.49	14.68	14.59	14.46
Wt. of mold (lb)	10.36	10.36	10.36	10.36	10.36
Net wt. of wet soil (lb)	3.84	4.13	4.32	4.23	4.10
Net wt of dry soil (lb)	3.50	3.72	3.71	3.49	3.26
y Density, (pcf)	104.89	111.59	111.28	104.57	97.69
Corrected Dry Density (pcf)					
Volume Factor	30	30	30	30	30

Data entered by: RV Date: 7-26-96
a checked by: [signature] Date: 7-26-96
FileName: TIPRUT-1 ADVANCED TERRA TESTING, INC

Proctor Compaction Test

, , UT-1



- Best Fit Curve
- Actual Data
- Zero Air VoidsCurve @ SG = 2.70

OPTIMUM MOISTURE CONTENT = 13.9 MAXIMUM DRY DENSITY = 113.5
ASTM D 1557 A, Rock correction applied? N

ADVANCED TERRA TESTING, INC.

PERMEABILITY DETERMINATION
FALLING HEAD
FIXED WALL

27/32

CLIENT	Titan Environmental	JOB NO.	2234-04
BORING NO.		SAMPLED	
DEPTH		TEST STARTED	7-28-96 CAL
SAMPLE NO.	UT-1	TEST FINISHED	8-7-96 CAL
SOIL DESCR.	Remolded 95% Mod Pt. @ OMC	SETUP NO.	1
SURCHARGE	200		

MOISTURE/DENSITY DATA	BEFORE TEST	AFTER TEST
Wt. Soil & Ring(s) (g)	386.9	404.5
Wt. Ring(s) (g)	93.0	93.0
Wt. Soil (g)	293.9	311.4
Wet Density PCF	122.3	120.5
Wt. Wet Soil & Pan (g)	302.4	319.9
Wt. Dry Soil & Pan (g)	266.2	266.2
Wt. Lost Moisture (g)	36.2	53.8
Wt. of Pan Only (g)	8.5	8.5
Wt. of Dry Soil (g)	257.7	257.7
Moisture Content %	14.1	20.9
Dry Density PCF	107.2	99.7
Max. Dry Density PCF	113.5	113.5
Percent Compaction	94.4	87.8

ELAPSED TIME (MIN)	BURETTE READING h1 (CC)	BURETTE READING h2 (CC)	PERCOLATION RATE FT/YEAR	CM/SEC
	0.2			
2599	10.8	10.8	0.14	1.4E-07
1427	14.2	14.2	0.09	8.4E-08
1440	16.8	16.8	0.07	6.5E-08
1440	18.6	18.6	0.05	4.6E-08
1440	20.2	20.2	0.04	4.1E-08
1440	21.6	21.6	0.04	3.7E-08
1469	23.0	23.0	0.04	3.6E-08
1440		24.4	0.04	3.7E-08

Data Entered By: NAA Date: 8-8-96
Date Checked By: [signature] Date: 8-8-96
Filename:TIFHUT1

ADVANCED TERRA TESTING, INC.

Rogers & Associates Engineering Corporation

28/32

REPORT OF RADON DIFFUSION COEFFICIENT MEASUREMENTS
(TIME-DEPENDENT DIFFUSION TEST METHOD RAE-SQAP-3.6)

Report Date: 9/3/96
Contract: C96009
By: BCR
Date Received: 8/96

Sample Identification: Titan Environmental

Sample ID	Moisture (Dry Wt. %)	Density (g/cm^3)	Radon Diffusion Coefficient (cm^2/s)	Saturation (Mρ/P)	Specific Gravity (g/cm^3)
UT-1	14.5%	1.72	9.1E-03	0.89	2.39

RAE

Post Office Box 330
Salt Lake City • Utah 84110
(801) 263-1600

Rogers & Associates Engineering Corporation

29/32

REPORT OF RADIUM CONTENT AND EMANATION COEFFICIENT MEASUREMENTS

(LAB PROCEDURE RAE-SQAP-3.1)

Report Date: 9/3/96

Contract: C960019

By: BCR

Date Received: 8/96

Sample Identification: Titan Environmental

Sample ID	Moisture (Dry Wt. %)	Radon Emanation Coefficient	Radium-226 (pCi/g)	Comments
UT-1	14.6%	0.22 ± 0.04	1.5 ± 0.3	

RAE

Post Office Box 330
Salt Lake City • Utah 84110
(801) 263-1600

Appendix C

31/32

...from the Professors who know it best...

PRINCIPLES & PRACTICE OF CIVIL ENGINEERING

—2nd Edition—

The most efficient and authoritative review book for the PE License Exam

Editor: MERLE C. POTTER, PhD, PE
Professor, Michigan State University

Authors:		
	Mackenzie L. Davis, PhD, PE	Water Quality
	Richard W. Furlong, PhD, PE	Structures
	David A. Hamilton, MS, PE	Hydrology
	Ronald Harichandran, PhD, PE	Structures
	Thomas L. Maleck, PhD, PE	Transportation
	George E. Mase, PhD	Mechanics
	Merle C. Potter, PhD, PE	Fluid Mechanics
	David C. Wiggert, PhD,PE	Hydraulics
	Thomas F. Wolff, PhD, PE	Soils

The authors are professors at Michigan State University, with the exception of R. W. Furlong, who teaches at the University of Texas at Austin and D. A. Hamilton who is employed by the Michigan Department of Natural Resources.

published by:

GREAT LAKES PRESS

P.O. Box 483

Okemos, MI 48805-0483

32/32

14.5 Other Useful Equations for Weight-Volume Problems

It is strongly recommended that weight-volume problems be solved using phase diagrams rather than only formulas, as completing a phase diagram clearly indicates whether sufficient information is known to complete the problem, whether information is insufficient and assumptions must be made, or whether too much information is present and the problem is overconstrained. For example, it may not be immediately apparent from the information given whether a soil is saturated until all quantities are calculated. Nevertheless, following are given additional useful equations that may be used to solve certain classes of weight-volume problems.

A very useful equation relating four different quantities is

$$Se = wG_s \tag{14.5.1}$$

For saturated soils (S = 100%) there results

$$e = wG_s \tag{14.5.2}$$

The relationships between the void ratio and porosity are

$$e = \frac{n}{1-n} \tag{14.5.3}$$

and

$$* \quad n = \frac{e}{1+e} \tag{14.5.4}$$

n = porosity
e = Volume of Voids / Volume of Solids

The total unit weight can be obtained as

$$\gamma = \frac{(G_s + Se)\gamma_w}{1+e} = \frac{(1+w)\gamma_w}{w/S + 1/G_s} \tag{14.5.5}$$

The dry unit weight can be obtained as

$$* \quad \gamma_d = \frac{G_s\gamma_w}{1+e} = \frac{G_s\gamma_w}{1+(wG_s/S)} \tag{14.5.6}$$

γ_d = Dry Bulk Density
G_s = Specific Gravity
γ_w = Density of Water

EXAMPLE 14.8

Rework example 14.6 using equations introduced in this section.

Solution.

$$Se = wG_s$$

$$S = wG_s/e = (.20)(2.65)/(0.800) = 0.6625 \text{ or } 66.3\%$$

$$n = \frac{e}{1+e} = \frac{0.800}{1+0.800} = 0.444$$

$$\gamma = \frac{(1+w)\gamma_w}{w/S + 1/G_s} = \frac{(1.20)(62.4)}{0.2/0.6625 + 1/2.65} = 110.2 \text{ lb/ft}^3$$

$$\gamma_d = \frac{G_s\gamma_w}{1+e} = \frac{(2.65)(62.4)}{1+0.800} = 91.9 \text{ lb/ft}^3$$

APPENDIX C

Radon Flux Measurments

1994 Results

Site Specific Sample Results (reference Figure 6-1)

(a) The mean radon flux for each region within each cell is as follows:

Cell 2 - Cover Area = 7.7 pCi/m^2-s (based on 225,882 m^2 area)
- Beach Areas = 23.3 pCi/m^2-s (based on 41,761 m^2 area)
- Standing Liquid Areas = 0 pCi/m^2-s (based on 2,982 m^2 area)

Cell 3 - Cover Area = 7.5 pCi/m^2-s (based on 82,762 m^2 area)
- Beach Areas = 39.7 pCi/m^2-s (based on 62,761 m^2 area)
- Standing Liquid Areas = 0 pCi/m^2-s (based on 143,335 m^2 area)

Note: Reference Appendix B of this report for entire summary for individual measurement results and specific sample region maps.

(b) Using the data presented above, we have calculated the total mean radon flux for each pile (cell) as follows:

Cell 2 = 10.0 pCi/m^2-s

$$\frac{(7.7)(225,882) + (23.3)(41,761) + (0)(2,982)}{270,625}$$

Cell 3 = 10.8 pCi/m^2-s

$$\frac{(7.5)(82,762) + (39.7)(62,761) + (0)(143,335)}{288,858}$$

1995 Results

6.0 SAMPLE RESULTS/CALCULATIONS

Referencing 40 CFR, Part 61, Subpart W, Appendix B, Method 115 - Monitoring for Radon-222 Emissions, Subsection 2.1.7 - Calculations, "the mean radon flux for each region of the pile and for the total pile shall be calculated and reported as follows:

(a) The individual radon flux calculations shall be made as provided in Appendix A EPA 86(1). The mean radon flux for each region of the pile shall be calculated by summing all individual flux measurements for the region and dividing by the total number of flux measurements for the region.

(b) The mean radon flux for the total uranium mill tailings pile shall be calculated as follows:

$$J_s = \frac{J_1A_1 + \ldots J_2A_2 \; [+] \; \ldots J_iA_i}{A_t}$$

Where: J_s = Mean flux for the total pile (pCi/m^2-s)
J_i = Mean flux measured in region i (pCi/m^2-s)
A_i = Area of region i (m^2)
A_t = Total area of the pile (m^2)

2.1.8 Reporting. The results of individual flux measurements, the approximate locations on the pile, and the mean radon flux for each region and the mean radon flux for the total stack [pile] shall be included in the emission test report. Any condition or unusual event that occurred during the measurements that could significantly affect the results should be reported."

Site Specific Sample Results (reference Figure 6-1)

(a) The mean radon flux for each region within each cell is as follows:

Cell 2
- Cover Area = 6.1 pCi/m^2-s (based on 225,882 m^2 area)
- Beach Areas = 28.4 pCi/m^2-s (based on 41,761 m^2 area)
- Standing Liquid Areas = 0 pCi/m^2-s (based on 2,982 m^2 area)

Cell 3
- Cover Area = 11.1 pCi/m^2-s (based on 82,762 m^2 area)
- Beach Areas = 44.8 pCi/m^2-s (based on 62,761 m^2 area)
- Standing Liquid Areas = 0 pCi/m^2-s (based on 143,335 m^2 area)

Note: Reference Appendix B of this report for entire summary for individual measurement results and specific sample region maps.

(b) Using the data presented above, we have calculated the total mean radon flux for each pile (cell) as follows:

Cell 2 = 9.5 pCi/m^2-s

$$\frac{(6.1)(225,882) + (28.4)(41,761) + (0)(2,982)}{270,625}$$

Cell 3 = 12.9 pCi/m^2-s

$$\frac{(11.1)(82,762) + (44.8)(62,761) + (0)(143,335)}{288,858}$$

APPENDIX D

HELP Model

Purpose: To determine the required soil cover thicknesses to minimize surface water infiltration through the White Mesa tailings impoundments so that precipitation will not fully penetrate the soil cover. The White Mesa Mill site is located in Blanding, Utah. The performance of the tailings cover was evaluated using the Hydrologic Evaluation of Landfill Performance (HELP) Model. The HELP model was developed to facilitate rapid, economical estimation of the amounts of surface runoff, subsurface drainage, and leachate that may be expected to result from the operation of a wide variety of possible cover designs.

Method: Determine the soil properties of the cover materials and climatic properties of Blanding, Utah based on existing database values previously collected, and acceptable default parameters. Input parameters into the computer modeling program "HELP" to determine the percolation through the cover materials. A variety of scenarios adjusting cover thicknesses were run to determine the optimum thicknesses of cover materials to eliminate percolation through the bottom cover layer. The modeled tailings cover consists of a compacted clay layer over the tailings, with a random fill soil layer covering the clay.

The model was developed for Cell 3 at the White Mesa Mill since it is the largest of the three cells to be covered (Cells 2, 3, and 4A). Figure 1 shows the location of the cells. The cover requirements determined for Cell 3 will be applied to the remaining cells as well. This is a conservative approach since the remaining cells are smaller in size and require less time and distance for precipitation runoff.

Results: A two-layer uranium mill tailings cover composed of a 2-foot layer of random fill over a 1-foot compacted clay layer will reduce percolation into the tailings material to a negligible quantity (see Appendix A for HELP results). As indicated by the model results, precipitation will either runoff the soil cover or be evaporated.

The cover thicknesses recommended above were also determined to be the minimum thickness requirements for White Mesa tailings covers based on results from radon flux calculations (see "Calculation of Radon Flux from the White Mesa Tailings Cover", 9/11/96). As indicated in the Radon Flux calculation, to restrict radon flux to 20 pCi/m2/sec, (Regulatory Guide 3.64), a cover consisting of 2-feet random fill and 1-foot compacted clay is required.

Parameters: The HELP model requires input of the following parameters for the cover materials:

- Weather Data:
  - Evapotranspiration
  - Precipitation
  - Temperature
  - Solar Radiation
- Soil and Design Data:
  - Landfill area (area of Cell 3)
  - Percent of area where runoff is possible
  - Moisture content initialization
- Cover Layer Data:
  - Layer type
  - Default soil/material texture number
  - Runoff curve number

Weather Data

Evapotranspiration and *solar radiation* data was input using the default parameters from Grand Junction, Colorado. Grand Junction is located north east of Blanding Utah in a similar climate and elevation. The elevation at Grand Junction is 4,600 feet and the elevation at Blanding Utah is 5,600 feet. Figure 1 in Appendix B shows the locations of Blanding and Grand Junction in relation to one another.

Precipitation data from 1988 to 1993 (skipping 1989) was obtained from Utah State University (see Appendix C). Daily precipitation values for the five years were input manually into the HELP model. *Temperature* data was obtained from the Dames & Moore (1978) and is also included in Appendix C. Daily temperature data was not available for manual entry therefore, the computer calculated mean monthly temperatures based on the default location (Grand Junction, Colorado). These values were then edited to match the actual mean monthly temperatures for Blanding, Utah.

Soil and Design Data

The surface area of Cell 3 at the White Mesa Mill, Blanding, Utah was used for the landfill area value. The surface area, as indicated on Figure 1, is 78.7 acres. It was assumed that runoff was possible over 100% of this area and that no rain would sit on the tailings cover.

Cover Layer Data

Layer Thickness:
A two-layer cover over approximately 28 feet of uranium mill tailings was used to run the HELP model. Actual cover thicknesses which would be constructed on site consist of 2-feet of random fill over a 1-foot compacted clay layer. This cover profile was adjusted for modeling purposes to account for freezing and thawing conditions. As indicated in the "Effects of Freezing on Uranium Mill Tailings Covers Calculation Brief" (6/17/96), 6.8 inches of the top random fill cover layer will be effected by freeze/thaw conditions at Blanding, Utah. This suggests that 6.8 inches of the top layer may not contribute to reductions of infiltration into the tailings piles. To conservatively compensate for effects from freezing and thawing, 6.8 inches were subtracted from the top random fill cover layer. Therefore, modeled layer thicknesses consisted of 17.2 inches of random fill over 12 inches of clay.

Layer Type:
The random fill soil layer was classified as a vertical percolation layer. Vertical percolation layers are composed of moderate to high permeability material that drains vertically, primarily as unsaturated flow. The clay layer was classified as a barrier soil liner. This material consists of low permeability soil designed to limit percolation/leakage and drains only vertically as a saturated flow.

Moisture Storage Parameters:
Required moisture storage parameters such as; porosity, field capacity, wilting point, initial soil water content, and permeability, are interrelated with the exception of permeability. The porosity must be greater than zero but less than 1. The field capacity must be between zero and 1 but must be smaller than the porosity. The wilting point must be greater than zero but less than the field capacity, and the initial moisture content must be greater than or equal to the wilting point and less than or equal to the porosity (U.S. EPA, 1994).

Based on these relations, actual measured porosity and permeability values were input for random fill (Chen and Associates, 1987) and clay (Advanced Terra Testing, 1996, sample UT-1). See Appendix D for physical property data. In addition, wilting point data for the layers was set equal to the long-term moisture content of the materials and the soil water content was adjusted to equal the optimum moisture content. Field capacity values just less than the porosity's were assumed to maintain the interrelationship of the parameters.

Runoff Curve Number
The runoff curve number was calculated by the HELP model based on a minimum surface slope of 0.2%, slope length of 1,200 feet, soil texture of the top layer, and vegetation. A slope length of 1,200 feet was assumed to be the maximum distance which precipitation would travel over the soil cover. The top layer on the tailings cover will be minimum 3" of rock riprap (sandstone) therefore, no vegetation will exist. This top layer, however, was not included in the model to determine percolation quantities.

References:

Advanced Terra Testing, 1996, Physical soil data, White Mesa Project, Blanding Utah, July 25, 1996.

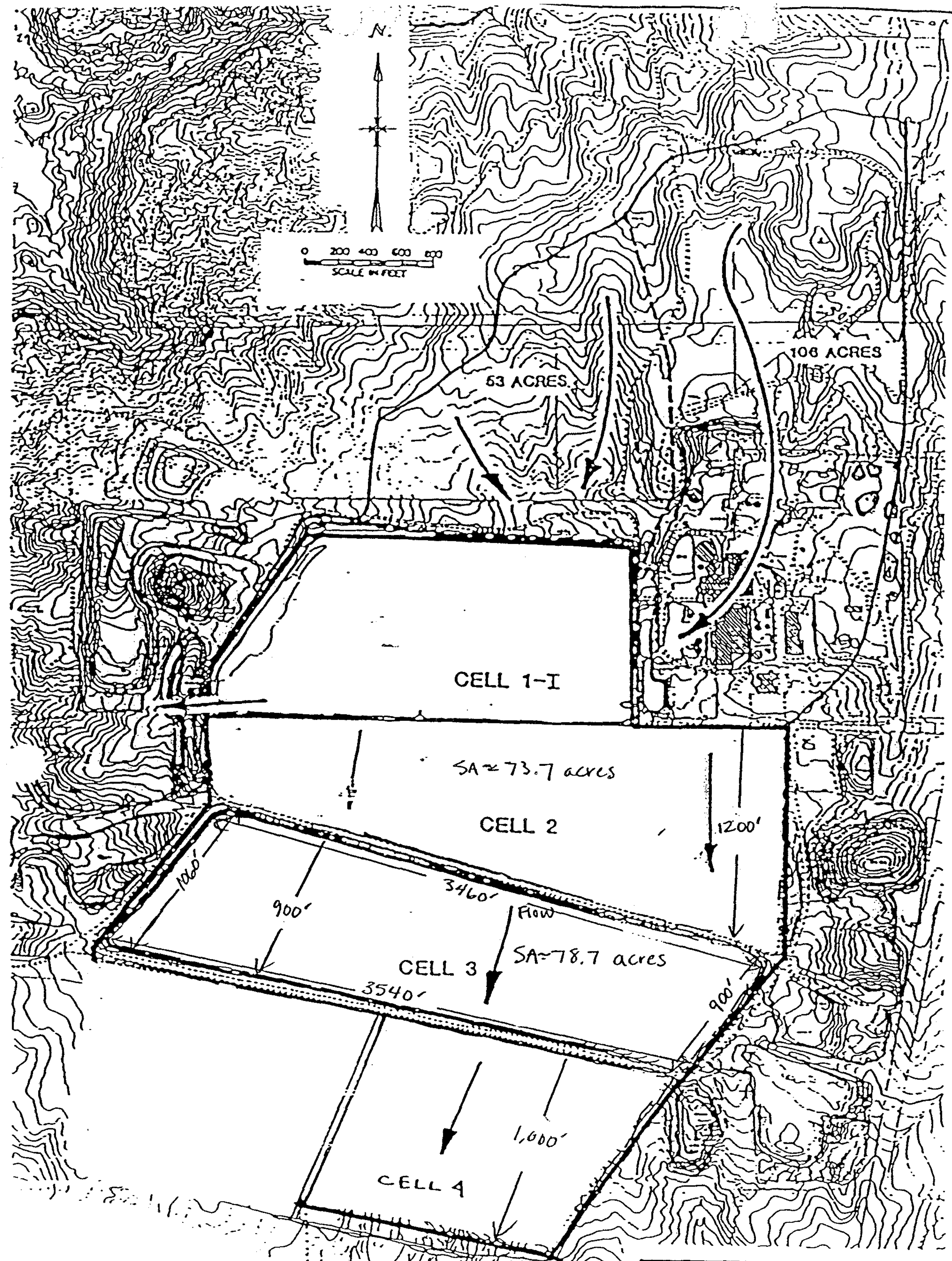
Chen and Associates, 1987. Physical soil data, White Mesa Project, Blanding, Utah.

Dames & Moore, 1978. "Environmental Report, White Mesa Uranium Project, San Juan County Utah", January 20, 1978, revised May 15, 1978.

Principles & Practice of Civil Engineering, 2nd Edition, 1996.

U.S. Environmental Protection Agency (EPA), 1994. "The Hydrologic Evaluation of Landfill Performance (HELP) Model", September, 1994.

Utah Climate Center, Utah State University, Daily Precipitation Values, Station #42073807, Blanding, Utah, January 1988 through December 1993.



Max distance water will travel over Cells = 1,200' + 900' + 1,000' = 3,100'

WHITE MESA PROJECT

SITE DRAINAGE

FIGURE: 1

PBA 9/96

5/34

Appendix A

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**             HELP MODEL VERSION 3.01    (14 OCTOBER 1994)                 **
**                DEVELOPED BY ENVIRONMENTAL LABORATORY                     **
**                  USAE WATERWAYS EXPERIMENT STATION                       **
**          FOR USEPA RISK REDUCTION ENGINEERING LABORATORY                 **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************
```

7/34

```
PRECIPITATION DATA FILE:     C:\HELP3\PRECIP.D4
TEMPERATURE DATA FILE:       C:\HELP3\TEMP2.D7
SOLAR RADIATION DATA FILE:   C:\HELP3\SOLAR.D13
EVAPOTRANSPIRATION DATA:     C:\HELP3\EVAP.D11
SOIL AND DESIGN DATA FILE:   C:\HELP3\efn-fin2.D10
OUTPUT DATA FILE:            C:\HELP3\efn-fin2.OUT


TIME:  14: 9     DATE:   9/11/1996


******************************************************************************

     TITLE:  EFN - White Mesa

******************************************************************************


     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
              WERE SPECIFIED BY THE USER.


                                  LAYER  1
                                  --------

                      TYPE 1 - VERTICAL PERCOLATION LAYER
                          MATERIAL TEXTURE NUMBER  88
            THICKNESS                   =      17.20    INCHES
            POROSITY                    =       0.3150 VOL/VOL
            FIELD CAPACITY              =       0.3140 VOL/VOL
            WILTING POINT               =       0.0980 VOL/VOL
            INITIAL SOIL WATER CONTENT  =       0.1180 VOL/VOL
            EFFECTIVE SAT. HYD. COND.   =  0.886999999000E-06 CM/SEC


                                  LAYER  2
```

TYPE 3 - BARRIER SOIL LINER
MATERIAL TEXTURE NUMBER 89

THICKNESS	=	12.00	INCHES
POROSITY	=	0.2800	VOL/VOL
FIELD CAPACITY	=	0.2799	VOL/VOL
WILTING POINT	=	0.1410	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.2800	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.369999995000E-07	CM/SEC

8/34

GENERAL DESIGN AND EVAPORATIVE ZONE DATA

NOTE: SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT SOIL DATA BASE USING SOIL TEXTURE #27 WITH BARE GROUND CONDITIONS, A SURFACE SLOPE OF 0.% AND A SLOPE LENGTH OF 1200. FEET.

SCS RUNOFF CURVE NUMBER	=	96.40	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	78.700	ACRES
EVAPORATIVE ZONE DEPTH	=	17.2	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	2.030	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	5.418	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	1.686	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	5.390	INCHES
TOTAL INITIAL WATER	=	5.390	INCHES
TOTAL SUBSURFACE INFLOW	=	0.00	INCHES/YEAR

EVAPOTRANSPIRATION AND WEATHER DATA

NOTE: EVAPOTRANSPIRATION DATA WAS OBTAINED FROM GRAND JUNCTION COLORADO

MAXIMUM LEAF AREA INDEX	=	0.00
START OF GROWING SEASON (JULIAN DATE)	=	109
END OF GROWING SEASON (JULIAN DATE)	=	293
AVERAGE ANNUAL WIND SPEED	=	8.10 MPH
AVERAGE 1ST QUARTER RELATIVE HUMIDITY	=	60.00 %
AVERAGE 2ND QUARTER RELATIVE HUMIDITY	=	36.00 %
AVERAGE 3RD QUARTER RELATIVE HUMIDITY	=	36.00 %
AVERAGE 4TH QUARTER RELATIVE HUMIDITY	=	57.00 %

NOTE: PRECIPITATION DATA FOR BLANDING UTAH WAS ENTERED BY THE USER.

NOTE: TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR GRAND JUNCTION COLORADO

NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

9/34

JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
27.50	32.90	38.10	47.10	57.40	66.90
73.60	70.90	63.00	51.60	38.50	28.90

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING COEFFICIENTS FOR GRAND JUNCTION COLORADO

STATION LATITUDE = 39.07 DEGREES

****

AVERAGE MONTHLY VALUES IN INCHES FOR YEARS 1988 THROUGH 1993

	JAN/JUL	FEB/AUG	MAR/SEP	APR/OCT	MAY/NOV	JUN/DEC
PRECIPITATION						
TOTALS	2.10	1.32	0.92	0.46	1.31	0.60
	1.17	1.37	1.16	1.24	1.07	1.18
STD. DEVIATIONS	1.85	1.43	0.72	0.37	0.71	0.62
	0.92	0.43	0.35	0.66	0.51	0.71
RUNOFF						
TOTALS	1.455	0.999	0.542	0.265	0.871	0.389
	0.774	0.885	0.802	0.785	0.713	0.568
STD. DEVIATIONS	1.967	1.206	0.425	0.240	0.472	0.494
	0.691	0.350	0.220	0.495	0.432	0.441
EVAPOTRANSPIRATION						
TOTALS	0.700	0.411	0.331	0.224	0.413	0.231
	0.353	0.490	0.424	0.394	0.402	0.534
STD. DEVIATIONS	0.072	0.246	0.236	0.110	0.296	0.201
	0.243	0.211	0.223	0.235	0.141	0.191
PERCOLATION/LEAKAGE THROUGH LAYER 2						
TOTALS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

10/34

DAILY AVERAGE HEAD ACROSS LAYER 2

AVERAGES	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
STD. DEVIATIONS	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

****

****

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1988 THROUGH 1993

	INCHES		CU. FEET	PERCENT
PRECIPITATION	13.90	(2.614)	3971537.7	100.00
RUNOFF	9.048	(2.4802)	2584718.25	65.081
EVAPOTRANSPIRATION	4.908	(0.7521)	1402180.62	35.306
PERCOLATION/LEAKAGE THROUGH FROM LAYER 2	0.00000	(0.00000)	0.000	0.00000
AVERAGE HEAD ACROSS TOP OF LAYER 2	0.000	(0.000)		
CHANGE IN WATER STORAGE	-0.054	(0.1827)	-15362.23	-0.387

****

****

PEAK DAILY VALUES FOR YEARS 1988 THROUGH 1993

	(INCHES)	(CU. FT.)
PRECIPITATION	1.33	379955.719
RUNOFF	1.684	481108.4370
PERCOLATION/LEAKAGE THROUGH LAYER 2	0.000000	0.00000
AVERAGE HEAD ACROSS LAYER 2	0.000	
SNOW WATER	2.96	845040.4370
MAXIMUM VEG. SOIL WATER (VOL/VOL)	0.1182	
MINIMUM VEG. SOIL WATER (VOL/VOL)	0.0962	

****

****

FINAL WATER STORAGE AT END OF YEAR 1993

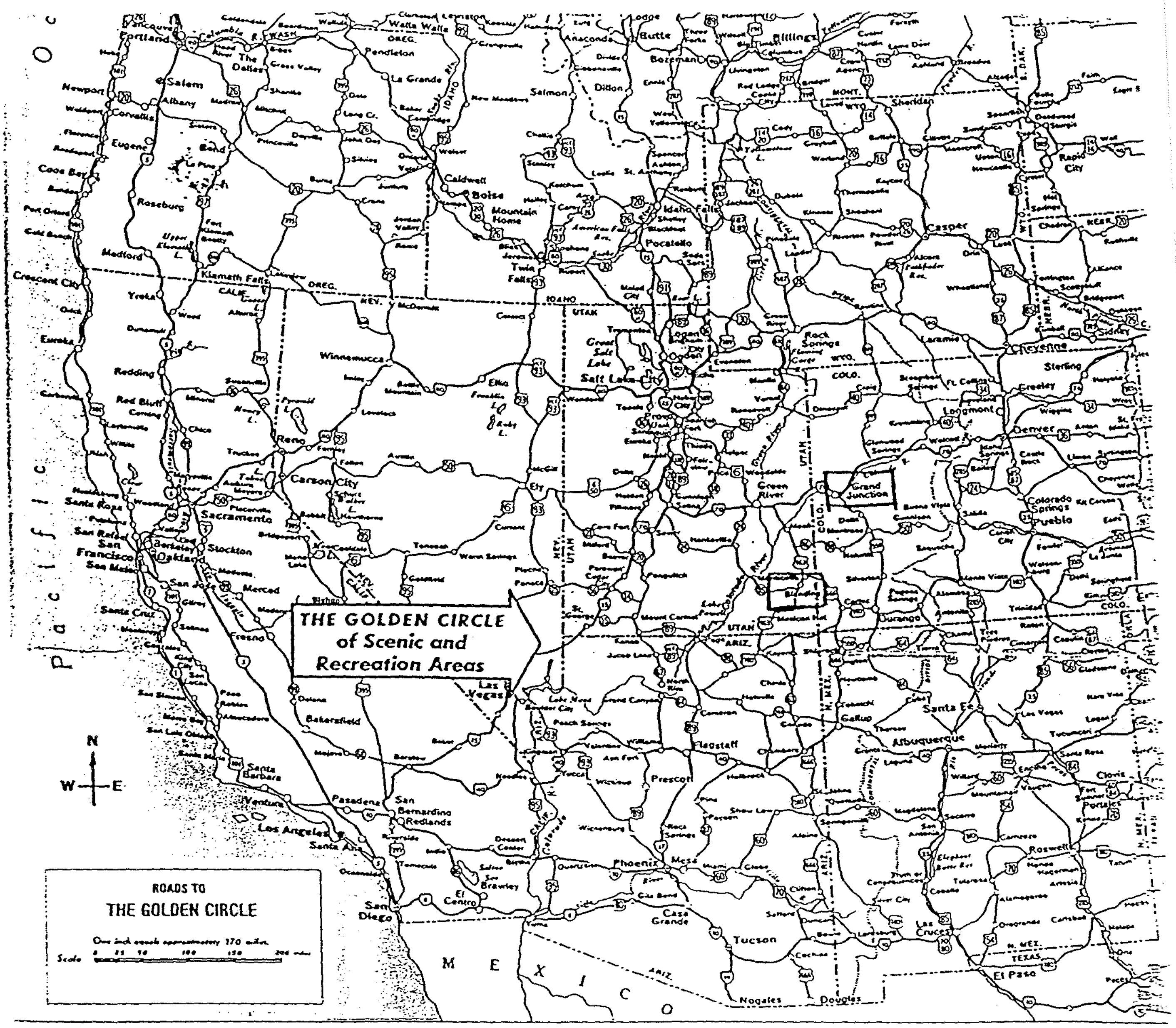
12/34

LAYER	(INCHES)	(VOL/VOL)
1	1.7607	0.1024
2	3.3600	0.2800
SNOW WATER	0.000	

****
****

Appendix B

Figure 1
Shows Location of Blanding to Grand Junction



Best Of The West . . .

tah combines the best of the West. 'ithin Utah's 85,000 square miles is a ɔncentrated collage of western folk-re, scenery and history.

:eer into Utah and sample some of our ve national parks, seven national mon-ɔents and two national recreation eas. Drive into our 43 state parks or ght national forests. Explore the ıuntry on this map and you'll soon :ho the statement first made by pio-ɔer settlers to Utah: "This Is the Place."

IVE NATIONAL PARKS

Southeastern Utah is the place for the world's greatest—and most concen-trated—repertory of stone arches. Arches National Park's trademark is Delicate Arch, although Landscape Arch is a world record-holder with a span of 291 feet.

WHITE WATER CANYONS

The Colorado River glides past Arches and churns into Canyonlands National Park 40 miles southwest. *National Geo-graphic* labels Canyonlands "the realm of rock and far horizon." The Colorado

Eighty percent of Utah's 1.2 million people live along the foothills of the Wasatch Mountains. Salt Lake City is not only the cultural and social hub of Utah, but also the international base for the Mormon Church.

The Utah Symphony, Ballet West, Utah Repertory Dance Theater and the Pio-neer Memorial Theater all lend a cos-mopolitan atmosphere to Salt Lake City. Professional sports are represented by the Golden Eagles hockey club and the Salt Lake Gulls baseball team.

Appendix C

Yearly Total (In) →

14/34

Daily Precipitation Values, Station #42073807, Blanding, Utah January, 1988 through February, 1994									
11.40		13.39		11.74		15.32		17.66	
↓ Date	Precipitation (inches)	↓ Date	Precipitation (inches)	↓ Date	Precipitation (inches)	↓ Date	Precipitation (inches)	↓ Date	Precipitation (inches)
1/1/88	0	1/1/90	0	1/1/91	0	1/1/92	0	1/1/93	0
1/2/88	0	1/2/90	0	1/2/91	0	1/2/92	0	1/2/93	0
1/3/88	0	1/3/90	0.2	1/3/91	0.15	1/3/92	0.04	1/3/93	0
1/4/88	0.06	1/4/90	0	1/4/91	0.96	1/4/92	0.31	1/4/93	0
1/5/88	0.19	1/5/90	0	1/5/91	0.08	1/5/92	0.02	1/5/93	0
1/6/88	0.17	1/6/90	0	1/6/91	0	1/6/92	0.42	1/6/93	0.34
1/7/88	0	1/7/90	0	1/7/91	0	1/7/92	0.03	1/7/93	0.36
1/8/88	0.01	1/8/90	0	1/8/91	0	1/8/92	0	1/8/93	1
1/9/88	0	1/9/90	0	1/9/91	0	1/9/92	0	1/9/93	0.01
1/10/88	0	1/10/90	0	1/10/91	0	1/10/92	0	1/10/93	0.51
1/11/88	0								
1/12/88	0	1/11/90	0	1/11/91	0	1/11/92	0	1/11/93	0.41
1/13/88	0	1/12/90	0	1/12/91	0	1/12/92	0	1/12/93	0
1/14/88	0	1/13/90	0.04	1/13/91	0.01	1/13/92	0	1/13/93	0.21
1/15/88	0	1/14/90	0	1/14/91	0	1/14/92	0	1/14/93	0.2
1/16/88	0	1/15/90	0.14	1/15/91	0.02	1/15/92	0	1/15/93	0
1/17/88	0.89	1/16/90	0.03	1/16/91	0	1/16/92	0	1/16/93	0.49
1/18/88	0.71	1/17/90	0.06	1/17/91	0	1/17/92	0	1/17/93	0.16
1/19/88	0	1/18/90	0.29	1/18/91	0	1/18/92	0	1/18/93	0.88
1/20/88	0	1/19/90	0.32	1/19/91	0	1/19/92	0	1/19/93	0.31
1/21/88	0	1/20/90	0	1/20/91	0	1/20/92	0	1/20/93	0
1/22/88	0	1/21/90	0	1/21/91	0	1/21/92	0	1/21/93	0
1/23/88	0	1/22/90	0	1/22/91	0	1/22/92	0	1/22/93	0
1/24/88	0	1/23/90	0	1/23/91	0	1/23/92	0	1/23/93	0
1/25/88	0	1/24/90	0	1/24/91	0	1/24/92	0	1/24/93	0
1/26/88	0	1/25/90	0	1/25/91	0	1/25/92	0	1/25/93	0
1/27/88	0	1/26/90	0	1/26/91	0	1/26/92	0	1/26/93	0
1/28/88	0	1/27/90	0	1/27/91	0	1/27/92	0	1/27/93	0
1/29/88	0	1/28/90	0	1/28/91	0	1/28/92	0	1/28/93	0
1/30/88	0	1/29/90	0	1/29/91	0	1/29/92	0	1/29/93	0
1/31/88	0	1/30/90	0	1/30/91	0	1/30/92	0	1/30/93	0.22
2/1/88	0	1/31/90	0.03	1/31/91	0	1/31/92	0	1/31/93	0.21
2/2/88	0.4	2/1/90	0.06	2/1/91	0	2/1/92	0	2/1/93	0.16
2/3/88	0.06	2/2/90	0.03	2/2/91	0	2/2/92	0	2/2/93	0
2/4/88	0	2/3/90	0	2/3/91	0	2/3/92	0	2/3/93	0
2/5/88	0	2/4/90	0	2/4/91	0	2/4/92	0.01	2/4/93	0
2/6/88	0	2/5/90	0	2/5/91	0	2/5/92	0	2/5/93	0
2/7/88	0	2/6/90	0	2/6/91	0	2/6/92	0	2/6/93	0
2/8/88	0	2/7/90	0	2/7/91	0	2/7/92	0	2/7/93	0
2/9/88	0	2/8/90	0	2/8/91	0	2/8/92	0.02	2/8/93	1.16
2/10/88	0	2/9/90	0	2/9/91	0	2/9/92	0	2/9/93	0.48
2/11/88	0	2/10/90	0	2/10/91	0	2/10/92	0.3	2/10/93	0.02
2/12/88	0	2/11/90	0	2/11/91	0	2/11/92	0.27	2/11/93	0
2/13/88	0	2/12/90	0	2/12/91	0	2/12/92	0.05	2/12/93	0
2/14/88	0	2/13/90	0	2/13/91	0	2/13/92	0.66	2/13/93	0
2/15/88	0	2/14/90	0.16	2/14/91	0	2/14/92	0	2/14/93	0.01
2/16/88	0	2/15/90	0.06	2/15/91	0	2/15/92	0	2/15/93	0.01
2/17/88	0	2/16/90	0	2/16/91	0.03	2/16/92	0.23	2/16/93	0.08
2/18/88	0	2/17/90	0	2/17/91	0.02	2/17/92	0	2/17/93	0
2/19/88	0	2/18/90	0.03	2/18/91	0	2/18/92	0	2/18/93	0.05
2/20/88	0	2/19/90	0.01	2/19/91	0	2/19/92	0	2/19/93	0.62
2/21/88	0	2/20/90	0.03	2/20/91	0	2/20/92	0	2/20/93	0.7
2/22/88	0	2/21/90	0	2/21/91	0	2/21/92	0	2/21/93	0
2/23/88	0	2/22/90	0	2/22/91	0	2/22/92	0	2/22/93	0
2/24/88	0	2/23/90	0	2/23/91	0	2/23/92	0	2/23/93	0
2/25/88	0	2/24/90	0	2/24/91	0	2/24/92	0	2/24/93	0.4
2/26/88	0	2/25/90	0	2/25/91	0	2/25/92	0	2/25/93	0.04
2/27/88	0.04	2/26/90	0	2/26/91	0	2/26/92	0	2/26/93	0
2/28/88	0	2/27/90	0	2/27/91	0	2/27/92	0	2/27/93	0
2/29/88	0	2/28/90	0	2/28/91	0.4	2/28/92	0	2/28/93	0
3/1/88	0	3/1/90	0.02	3/1/91	0.9	2/29/92	0	3/1/93	0
3/2/88	0	3/2/90	0	3/2/91	0	3/1/92	0	3/2/93	0
3/3/88	0	3/3/90	0	3/3/91	0	3/2/92	0	3/3/93	0
3/4/88	0	3/4/90	0	3/4/91	0	3/3/92	0.34	3/4/93	0

TABLE 1

17/34

Daily Precipitation Values, Station #42073807, Blanding, Utah
January, 1988 through February, 1994

Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)
3/5/88	0	3/5/90	0	3/5/91	0	3/4/92	0	3/5/93	0
3/6/88	0.01	3/6/90	0.01	3/6/91	0	3/5/92	0	3/6/93	0
3/7/88	0	3/7/90	0	3/7/91	0	3/6/92	0	3/7/93	0
3/8/88	0	3/8/90	0	3/8/91	0	3/7/92	0	3/8/93	0
3/9/88	0	3/9/90	0	3/9/91	0	3/8/92	0.25	3/9/93	0
3/10/88	0.01	3/10/90	0.02	3/10/91	0	3/9/92	0.03	3/10/93	0
3/11/88	0	3/11/90	0.15	3/11/91	0	3/10/92	0	3/11/93	0
3/12/88	0	3/12/90	0.23	3/12/91	0	3/11/92	0	3/12/93	0
3/13/88	0	3/13/90	0.06	3/13/91	0	3/12/92	0	3/13/93	0
3/14/88	0	3/14/90	0	3/14/91	0.06	3/13/92	0	3/14/93	0
3/15/88	0	3/15/90	0	3/15/91	0.01	3/14/92	0	3/15/93	0
3/16/88	0.01	3/16/90	0	3/16/91	0	3/15/92	0	3/16/93	0
3/17/88	0	3/17/90	0	3/17/91	0	3/16/92	0	3/17/93	0
3/18/88	0	3/18/90	0	3/18/91	0	3/17/92	0	3/18/93	0.19
3/19/88	0	3/19/90	0	3/19/91	0.03	3/18/92	0	3/19/93	0
3/20/88	0	3/20/90	0	3/20/91	0	3/19/92	0	3/20/93	0
3/21/88	0	3/21/90	0	3/21/91	0.14	3/20/92	0	3/21/93	0
3/22/88	0	3/22/90	0	3/22/91	0	3/21/92	0.03	3/22/93	0
3/23/88	0	3/23/90	0	3/23/91	0	3/22/92	0.02	3/23/93	0
3/24/88	0	3/24/90	0	3/24/91	0	3/23/92	0.05	3/24/93	0
3/25/88	0	3/25/90	0	3/25/91	0	3/24/92	0.02	3/25/93	0
3/26/88	0	3/26/90	0	3/26/91	0.26	3/25/92	0	3/26/93	0.06
3/27/88	0	3/27/90	0	3/27/91	0	3/26/92	0	3/27/93	0.47
3/28/88	0	3/28/90	0	3/28/91	0	3/27/92	0.5	3/28/93	0
3/29/88	0	3/29/90	0	3/29/91	0	3/28/92	0.37	3/29/93	0.01
3/30/88	0	3/30/90	0.08	3/30/91	0	3/29/92	0	3/30/93	0
3/31/88	0	3/31/90	0	3/31/91	0	3/30/92	0.13	3/31/93	0
4/1/88	0	4/1/90	0	4/1/91	0	3/31/92	0.11	4/1/93	0
4/2/88	0	4/2/90	0	4/2/91	0	4/1/92	0.05	4/2/93	0
4/3/88	0	4/3/90	0	4/3/91	0	4/2/92	0	4/3/93	0
4/4/88	0.02	4/4/90	0	4/4/91	0	4/3/92	0	4/4/93	0.03
4/5/88	0	4/5/90	0	4/5/91	0	4/4/92	0	4/5/93	0.04
4/6/88	0	4/6/90	0	4/6/91	0	4/5/92	0	4/6/93	0.5
4/7/88	0	4/7/90	0.06	4/7/91	0	4/6/92	0	4/7/93	0
4/8/88	0	4/8/90	0.11	4/8/91	0	4/7/92	0	4/8/93	0
4/9/88	0	4/9/90	0	4/9/91	0	4/8/92	0	4/9/93	0
4/10/88	0	4/10/90	0	4/10/91	0	4/9/92	0	4/10/93	0
4/11/88	0	4/11/90	0	4/11/91	0	4/10/92	0	4/11/93	0
4/12/88	0	4/12/90	0	4/12/91	0	4/11/92	0	4/12/93	0
4/13/88	0	4/13/90	0	4/13/91	0	4/12/92	0	4/13/93	0
4/14/88	0.06	4/14/90	0	4/14/91	0	4/13/92	0	4/14/93	0
4/15/88	0.2	4/15/90	0	4/15/91	0	4/14/92	0	4/15/93	0
4/16/88	0.16	4/16/90	0	4/16/91	0	4/15/92	0.03	4/16/93	0.02
4/17/88	0.2	4/17/90	0	4/17/91	0	4/16/92	0.03	4/17/93	0
4/18/88	0.02	4/18/90	0	4/18/91	0	4/17/92	0	4/18/93	0
4/19/88	0	4/19/90	0	4/19/91	0	4/18/92	0	4/19/93	0
4/20/88	0	4/20/90	0	4/20/91	0	4/19/92	0	4/20/93	0
4/21/88	0.01	4/21/90	0	4/21/91	0	4/20/92	0	4/21/93	0
4/22/88	0.08	4/22/90	0	4/22/91	0	4/21/92	0	4/22/93	0
4/23/88	0.01	4/23/90	0	4/23/91	0.01	4/22/92	0	4/23/93	0
4/24/88	0.02	4/24/90	0.48	4/24/91	0	4/23/92	0	4/24/93	0
4/25/88	0	4/25/90	0	4/25/91	0	4/24/92	0	4/25/93	0
4/26/88	0	4/26/90	0	4/26/91	0	4/25/92	0	4/26/93	0
4/27/88	0	4/27/90	0	4/27/91	0	4/26/92	0	4/27/93	0
4/28/88	0	4/28/90	0	4/28/91	0	4/27/92	0	4/28/93	0
4/29/88	0	4/29/90	0.09	4/29/91	0	4/28/92	0	4/29/93	0
4/30/88	0	4/30/90	0.06	4/30/91	0	4/29/92	0	4/30/93	0
5/1/88	0	5/1/90	0.83	5/1/91	0	4/30/92	0	5/1/93	0
5/2/88	0	5/2/90	0	5/2/91	0	5/1/92	0	5/2/93	0
5/3/88	0	5/3/90	0	5/3/91	0	5/2/92	0	5/3/93	0
5/4/88	0	5/4/90	0	5/4/91	0	5/3/92	0	5/4/93	0.05
5/5/88	0	5/5/90	0	5/5/91	0	5/4/92	0.07	5/5/93	0.5
5/6/88	0	5/6/90	0	5/6/91	0	5/5/92	0	5/6/93	0
5/7/88	0	5/7/90	0	5/7/91	0	5/6/92	0	5/7/93	0.06

Table 1 (cont)

18/34

Daily Precipitation Values, Station #42073807, Blanding, Utah
January, 1988 through February, 1994

Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)
5/8/88	0	5/8/90	0	5/8/91	0	5/7/92	0.19	5/8/93	0.15
5/9/88	0	5/9/90	0	5/9/91	0	5/8/92	0	5/9/93	0
5/10/88	0	5/10/90	0	5/10/91	0	5/9/92	0.96	5/10/93	0
5/11/88	0	5/11/90	0	5/11/91	0	5/10/92	0	5/11/93	0
5/12/88	0	5/12/90	0	5/12/91	0	5/11/92	0	5/12/93	0
5/13/88	0	5/13/90	0	5/13/91	0	5/12/92	0	5/13/93	0
5/14/88	0	5/14/90	0	5/14/91	0	5/13/92	0	5/14/93	0
5/15/88	0	5/15/90	0	5/15/91	0.06	5/14/92	0	5/15/93	0.02
5/16/88	0	5/16/90	0	5/16/91	0	5/15/92	0	5/16/93	0.08
5/17/88	0.64	5/17/90	0	5/17/91	0	5/16/92	0	5/17/93	0.35
5/18/88	0.3	5/18/90	0	5/18/91	0	5/17/92	0	5/18/93	0
5/19/88	0.15	5/19/90	0	5/19/91	0	5/18/92	0	5/19/93	0
5/20/88	0	5/20/90	0	5/20/91	0	5/19/92	0.06	5/20/93	0.01
5/21/88	0	5/21/90	0	5/21/91	0	5/20/92	0.05	5/21/93	0
5/22/88	0	5/22/90	0	5/22/91	0	5/21/92	0.06	5/22/93	0
5/23/88	0	5/23/90	0	5/23/91	0	5/22/92	0.36	5/23/93	0
5/24/88	0	5/24/90	0	5/24/91	0	5/23/92	0.02	5/24/93	0
5/25/88	0	5/25/90	0	5/25/91	0	5/24/92	0.2	5/25/93	0.05
5/26/88	0	5/26/90	0	5/26/91	0	5/25/92	0.15	5/26/93	0.11
5/27/88	0	5/27/90	0	5/27/91	0	5/26/92	0.13	5/27/93	0.19
5/28/88	0	5/28/90	0	5/28/91	0	5/27/92	0.05	5/28/93	0.05
5/29/88	0.17	5/29/90	0.02	5/29/91	0	5/28/92	0	5/29/93	0
5/30/88	0.01	5/30/90	0	5/30/91	0	5/29/92	0.03	5/30/93	0
5/31/88	0	5/31/90	0	5/31/91	0.43	5/30/92	0	5/31/93	0
6/1/88	0	6/1/90	0	6/1/91	0	5/31/92	0	6/1/93	0
6/2/88	0	6/2/90	0	6/2/91	0	6/1/92	0	6/2/93	0
6/3/88	0	6/3/90	0	6/3/91	0	6/2/92	0	6/3/93	0
6/4/88	0	6/4/90	0	6/4/91	0	6/3/92	0	6/4/93	0
6/5/88	0	6/5/90	0	6/5/91	0	6/4/92	0.01	6/5/93	0
6/6/88	0	6/6/90	0	6/6/91	0	6/5/92	0.03	6/6/93	0.01
6/7/88	0	6/7/90	0	6/7/91	0	6/6/92	0	6/7/93	0.01
6/8/88	0	6/8/90	0	6/8/91	0	6/7/92	0	6/8/93	0.06
6/9/88	0	6/9/90	0.04	6/9/91	0	6/8/92	0.16	6/9/93	0
6/10/88	0	6/10/90	1.09	6/10/91	0	6/9/92	0	6/10/93	0
6/11/88	0	6/11/90	0	6/11/91	0	6/10/92	0	6/11/93	0
6/12/88	0	6/12/90	0	6/12/91	0	6/11/92	0	6/12/93	0
6/13/88	0	6/13/90	0	6/13/91	0	6/12/92	0	6/13/93	0
6/14/88	0	6/14/90	0	6/14/91	0.05	6/13/92	0	6/14/93	0
6/15/88	0	6/15/90	0	6/15/91	0	6/14/92	0	6/15/93	0
6/16/88	0	6/16/90	0	6/16/91	0	6/15/92	0	6/16/93	0
6/17/88	0	6/17/90	0	6/17/91	0	6/16/92	0	6/17/93	0.04
6/18/88	0	6/18/90	0	6/18/91	0	6/17/92	0	6/18/93	0
6/19/88	0	6/19/90	0	6/19/91	0	6/18/92	0	6/19/93	0
6/20/88	0	6/20/90	0	6/20/91	0	6/19/92	0	6/20/93	0
6/21/88	0	6/21/90	0	6/21/91	0	6/20/92	0	6/21/93	0
6/22/88	0.02	6/22/90	0	6/22/91	0	6/21/92	0	6/22/93	0
6/23/88	0.01	6/23/90	0	6/23/91	0	6/22/92	0	6/23/93	0
6/24/88	0.05	6/24/90	0	6/24/91	0	6/23/92	0	6/24/93	0
6/25/88	0.27	6/25/90	0	6/25/91	0	6/24/92	0	6/25/93	0
6/26/88	0.11	6/26/90	0	6/26/91	0	6/25/92	0.08	6/26/93	0
6/27/88	0.52	6/27/90	0	6/27/91	0	6/26/92	0	6/27/93	0
6/28/88	0.42	6/28/90	0	6/28/91	0	6/27/92	0	6/28/93	0
6/29/88	0	6/29/90	0	6/29/91	0	6/28/92	0.01	6/29/93	0
6/30/88	0	6/30/90	0	6/30/91	0	6/29/92	0	6/30/93	0
7/1/88	0	7/1/90	0	7/1/91	0	6/30/92	0	7/1/93	0
7/2/88	0	7/2/90	0	7/2/91	0	7/1/92	0	7/2/93	0
7/3/88	0	7/3/90	0	7/3/91	0	7/2/92	0	7/3/93	0
7/4/88	0	7/4/90	0	7/4/91	0	7/3/92	0	7/4/93	0
7/5/88	0	7/5/90	0	7/5/91	0	7/4/92	0	7/5/93	0
7/6/88	0	7/6/90	0	7/6/91	0	7/5/92	0	7/6/93	0
7/7/88	0	7/7/90	0.78	7/7/91	0	7/6/92	0	7/7/93	0
7/8/88	0	7/8/90	0.73	7/8/91	0.1	7/7/92	0	7/8/93	0
7/9/88	0	7/9/90	0.02	7/9/91	0.45	7/8/92	0.4	7/9/93	0
7/10/88	0	7/10/90	0	7/10/91	0.01	7/9/92	0	7/10/93	0

Table 1 (cont.)

19/34

Daily Precipitation Values, Station #42073807, Blanding, Utah
January, 1988 through February, 1994

Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)
7/11/88	0	7/11/90	0	7/11/91	0	7/10/92	0	7/11/93	0
7/12/88	0	7/12/90	0	7/12/91	0	7/11/92	0	7/12/93	0
7/13/88	0	7/13/90	0	7/13/91	0	7/12/92	1.33	7/13/93	0
7/14/88	0	7/14/90	0.05	7/14/91	0	7/13/92	0.02	7/14/93	0
7/15/88	0	7/15/90	0	7/15/91	0	7/14/92	0	7/15/93	0
7/16/88	0	7/16/90	0	7/16/91	0	7/15/92	0	7/16/93	0
7/17/88	0.05	7/17/90	0	7/17/91	0	7/16/92	0	7/17/93	0
7/18/88	0	7/18/90	0.01	7/18/91	0	7/17/92	0	7/18/93	0
7/19/88	0	7/19/90	0	7/19/91	0	7/18/92	0.08	7/19/93	0
7/20/88	0	7/20/90	0	7/20/91	0.28	7/19/92	0	7/20/93	0
7/21/88	0	7/21/90	0.03	7/21/91	0	7/20/92	0	7/21/93	0
7/22/88	0	7/22/90	0	7/22/91	0	7/21/92	0	7/22/93	0
7/23/88	0	7/23/90	0.01	7/23/91	0.04	7/22/92	0.1	7/23/93	0
7/24/88	0	7/24/90	0.02	7/24/91	0.23	7/23/92	0.08	7/24/93	0.01
7/25/88	0	7/25/90	0.05	7/25/91	0.08	7/24/92	0	7/25/93	0
7/26/88	0.16	7/26/90	0	7/26/91	0.01	7/25/92	0.17	7/26/93	0
7/27/88	0	7/27/90	0	7/27/91	0	7/26/92	0	7/27/93	0
7/28/88	0	7/28/90	0.02	7/28/91	0	7/27/92	0	7/28/93	0
7/29/88	0.13	7/29/90	0	7/29/91	0	7/28/92	0.02	7/29/93	0
7/30/88	0.05	7/30/90	0.19	7/30/91	0	7/29/92	0	7/30/93	0
7/31/88	0.12	7/31/90	0	7/31/91	0	7/30/92	0	7/31/93	0
8/1/88	0.13	8/1/90	0	8/1/91	0.03	7/31/92	0	8/1/93	0
8/2/88	0	8/2/90	0.25	8/2/91	0.04	8/1/92	0	8/2/93	0
8/3/88	0	8/3/90	0	8/3/91	0.08	8/2/92	0	8/3/93	0
8/4/88	0	8/4/90	0	8/4/91	0	8/3/92	0	8/4/93	0.01
8/5/88	0.38	8/5/90	0	8/5/91	0.01	8/4/92	0	8/5/93	0
8/6/88	0.02	8/6/90	0	8/6/91	0.56	8/5/92	0.02	8/6/93	0.03
8/7/88	0	8/7/90	0	8/7/91	0	8/6/92	0.01	8/7/93	0.03
8/8/88	0	8/8/90	0	8/8/91	0	8/7/92	0	8/8/93	0.03
8/9/88	0	8/9/90	0	8/9/91	0	8/8/92	0	8/9/93	0.03
8/10/88	0	8/10/90	0	8/10/91	0	8/9/92	0.03	8/10/93	0.01
8/11/88	0.04	8/11/90	0.04	8/11/91	0	8/10/92	0	8/11/93	0
8/12/88	0.07	8/12/90	0	8/12/91	0.36	8/11/92	0.04	8/12/93	0
8/13/88	0	8/13/90	0.15	8/13/91	0	8/12/92	0	8/13/93	0
8/14/88	0	8/14/90	0.07	8/14/91	0	8/13/92	0	8/14/93	0
8/15/88	0.09	8/15/90	0.05	8/15/91	0.01	8/14/92	0	8/15/93	0
8/16/88	0.05	8/16/90	0.24	8/16/91	0	8/15/92	0	8/16/93	0
8/17/88	0	8/17/90	0	8/17/91	0	8/16/92	0	8/17/93	0
8/18/88	0	8/18/90	0	8/18/91	0.06	8/17/92	0.19	8/18/93	0
8/19/88	0	8/19/90	0	8/19/91	0	8/18/92	0	8/19/93	0.03
8/20/88	0.24	8/20/90	0	8/20/91	0	8/19/92	0	8/20/93	0
8/21/88	0.15	8/21/90	0	8/21/91	0	8/20/92	0	8/21/93	0.02
8/22/88	0	8/22/90	0	8/22/91	0	8/21/92	0	8/22/93	0
8/23/88	0	8/23/90	0	8/23/91	0	8/22/92	0.37	8/23/93	0
8/24/88	0	8/24/90	0	8/24/91	0	8/23/92	0.16	8/24/93	0
8/25/88	0	8/25/90	0	8/25/91	0	8/24/92	0	8/25/93	0.08
8/26/88	0	8/26/90	0	8/26/91	0	8/25/92	0	8/26/93	0.74
8/27/88	0	8/27/90	0	8/27/91	0.01	8/26/92	0	8/27/93	0
8/28/88	0	8/28/90	0	8/28/91	0	8/27/92	0	8/28/93	0.73
8/29/88	0	8/29/90	0	8/29/91	0	8/28/92	0	8/29/93	0
8/30/88	0.18	8/30/90	0	8/30/91	0	8/29/92	0	8/30/93	0
8/31/88	0.47	8/31/90	0	8/31/91	0.02	8/30/92	0.28	8/31/93	0.05
9/1/88	0.01	9/1/90	0.01	9/1/91	0	8/31/92	0.16	9/1/93	0
9/2/88	0	9/2/90	0.32	9/2/91	0	9/1/92	0	9/2/93	0
9/3/88	0	9/3/90	0.1	9/3/91	0	9/2/92	0	9/3/93	0
9/4/88	0	9/4/90	0	9/4/91	0	9/3/92	0	9/4/93	0
9/5/88	0	9/5/90	0.08	9/5/91	0	9/4/92	0	9/5/93	0
9/6/88	0	9/6/90	0.1	9/6/91	0.93	9/5/92	0	9/6/93	0
9/7/88	0	9/7/90	0	9/7/91	0.25	9/6/92	0	9/7/93	0
9/8/88	0	9/8/90	0	9/8/91	0	9/7/92	0	9/8/93	0
9/9/88	0	9/9/90	0	9/9/91	0	9/8/92	0	9/9/93	0
9/10/88	0.32	9/10/90	0	9/10/91	0	9/9/92	0	9/10/93	0
9/11/88	0.05	9/11/90	0	9/11/91	0.13	9/10/92	0	9/11/93	0
9/12/88	0.58	9/12/90	0	9/12/91	0	9/11/92	0	9/12/93	0.01

Table 1 (cont)

20/34

Daily Precipitation Values, Station #42073807, Blanding, Utah
January, 1988 through February, 1994

Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)
9/13/88	0	9/13/90	0	9/13/91	0.01	9/12/92	0	9/13/93	0.6
9/14/88	0	9/14/90	0	9/14/91	0	9/13/92	0	9/14/93	0
9/15/88	0	9/15/90	0	9/15/91	0	9/14/92	0	9/15/93	0
9/16/88	0	9/16/90	0	9/16/91	0	9/15/92	0.13	9/16/93	0
9/17/88	0	9/17/90	0	9/17/91	0	9/16/92	0	9/17/93	0
9/18/88	0	9/18/90	0.63	9/18/91	0	9/17/92	0	9/18/93	0.22
9/19/88	0	9/19/90	0	9/19/91	0	9/18/92	0.22	9/19/93	0
9/20/88	0	9/20/90	0.16	9/20/91	0	9/19/92	0.47	9/20/93	0
9/21/88	0.08	9/21/90	0	9/21/91	0	9/20/92	0.08	9/21/93	0
9/22/88	0	9/22/90	0	9/22/91	0	9/21/92	0	9/22/93	0
9/23/88	0	9/23/90	0.06	9/23/91	0	9/22/92	0	9/23/93	0
9/24/88	0	9/24/90	0	9/24/91	0	9/23/92	0	9/24/93	0
9/25/88	0	9/25/90	0	9/25/91	0	9/24/92	0	9/25/93	0
9/26/88	0	9/26/90	0	9/26/91	0	9/25/92	0	9/26/93	0
9/27/88	0.03	9/27/90	0	9/27/91	0	9/26/92	0	9/27/93	0
9/28/88	0	9/28/90	0.23	9/28/91	0	9/27/92	0	9/28/93	0
9/29/88	0	9/29/90	0	9/29/91	0	9/28/92	0	9/29/93	0
9/30/88	0	9/30/90	0	9/30/91	0	9/29/92	0	9/30/93	0
10/1/88	0	10/1/90	0.01	10/1/91	0	9/30/92	0	10/1/93	0
10/2/88	0	10/2/90	1.1	10/2/91	0	10/1/92	0	10/2/93	0
10/3/88	0	10/3/90	0.02	10/3/91	0	10/2/92	0	10/3/93	0
10/4/88	0	10/4/90	0	10/4/91	0	10/3/92	0	10/4/93	0
10/5/88	0	10/5/90	0	10/5/91	0	10/4/92	0	10/5/93	0
10/6/88	0.02	10/6/90	0	10/6/91	0	10/5/92	0	10/6/93	0.61
10/7/88	0.04	10/7/90	0.1	10/7/91	0	10/6/92	0	10/7/93	0.21
10/8/88	0.02	10/8/90	0	10/8/91	0	10/7/92	0	10/8/93	0.19
10/9/88	0	10/9/90	0	10/9/91	0	10/8/92	0	10/9/93	0
10/10/88	0	10/10/90	0	10/10/91	0	10/9/92	0	10/10/93	0.01
10/11/88	0	10/11/90	0	10/11/91	0	10/10/92	0	10/11/93	0.1
10/12/88	0	10/12/90	0	10/12/91	0	10/11/92	0	10/12/93	0
10/13/88	0	10/13/90	0	10/13/91	0	10/12/92	0	10/13/93	0
10/14/88	0	10/14/90	0	10/14/91	0	10/13/92	0	10/14/93	0
10/15/88	0	10/15/90	0	10/15/91	0	10/14/92	0	10/15/93	0
10/16/88	0	10/16/90	0	10/16/91	0	10/15/92	0	10/16/93	0.09
10/17/88	0	10/17/90	0	10/17/91	0	10/16/92	0	10/17/93	0.2
10/18/88	0	10/18/90	0.2	10/18/91	0	10/17/92	0	10/18/93	0.02
10/19/88	0	10/19/90	0.28	10/19/91	0	10/18/92	0	10/19/93	0
10/20/88	0	10/20/90	0.11	10/20/91	0	10/19/92	0	10/20/93	0
10/21/88	0	10/21/90	0	10/21/91	0	10/20/92	0	10/21/93	0
10/22/88	0	10/22/90	0	10/22/91	0.02	10/21/92	0.11	10/22/93	0
10/23/88	0	10/23/90	0	10/23/91	0	10/22/92	0	10/23/93	0
10/24/88	0	10/24/90	0	10/24/91	0.08	10/23/92	0	10/24/93	0
10/25/88	0	10/25/90	0	10/25/91	0	10/24/92	0.37	10/25/93	0
10/26/88	0	10/26/90	0	10/26/91	0	10/25/92	0.15	10/26/93	0
10/27/88	0	10/27/90	0	10/27/91	0.69	10/26/92	0	10/27/93	0
10/28/88	0	10/28/90	0	10/28/91	0.26	10/27/92	0.04	10/28/93	0
10/29/88	0	10/29/90	0	10/29/91	0.26	10/28/92	0.26	10/29/93	0
10/30/88	0.02	10/30/90	0	10/30/91	0.1	10/29/92	0.12	10/30/93	0
10/31/88	0	10/31/90	0	10/31/91	0	10/30/92	0.22	10/31/93	0
11/1/88	0	11/1/90	0	11/1/91	0	10/31/92	0.19	11/1/93	0
11/2/88	0	11/2/90	0.35	11/2/91	0	11/1/92	0	11/2/93	0
11/3/88	0	11/3/90	0.37	11/3/91	0	11/2/92	0	11/3/93	0
11/4/88	0	11/4/90	0	11/4/91	0	11/3/92	0	11/4/93	0
11/5/88	0	11/5/90	0	11/5/91	0	11/4/92	0	11/5/93	0
11/6/88	0	11/6/90	0.01	11/6/91	0	11/5/92	0	11/6/93	0
11/7/88	0	11/7/90	0.12	11/7/91	0	11/6/92	0	11/7/93	0
11/8/88	0	11/8/90	0	11/8/91	0	11/7/92	0	11/8/93	0
11/9/88	0	11/9/90	0	11/9/91	0	11/8/92	0	11/9/93	0
11/10/88	0	11/10/90	0	11/10/91	0.03	11/9/92	0	11/10/93	0
11/11/88	0.56	11/11/90	0	11/11/91	0	11/10/92	0.14	11/11/93	0.64
11/12/88	0	11/12/90	0	11/12/91	0	11/11/92	0	11/12/93	0.3
11/13/88	0	11/13/90	0	11/13/91	0	11/12/92	0	11/13/93	0.14
11/14/88	0	11/14/90	0	11/14/91	0.49	11/13/92	0	11/14/93	0
11/15/88	0.25	11/15/90	0	11/15/91	0.95	11/14/92	0	11/15/93	0

Table 1 (cont)

21/34

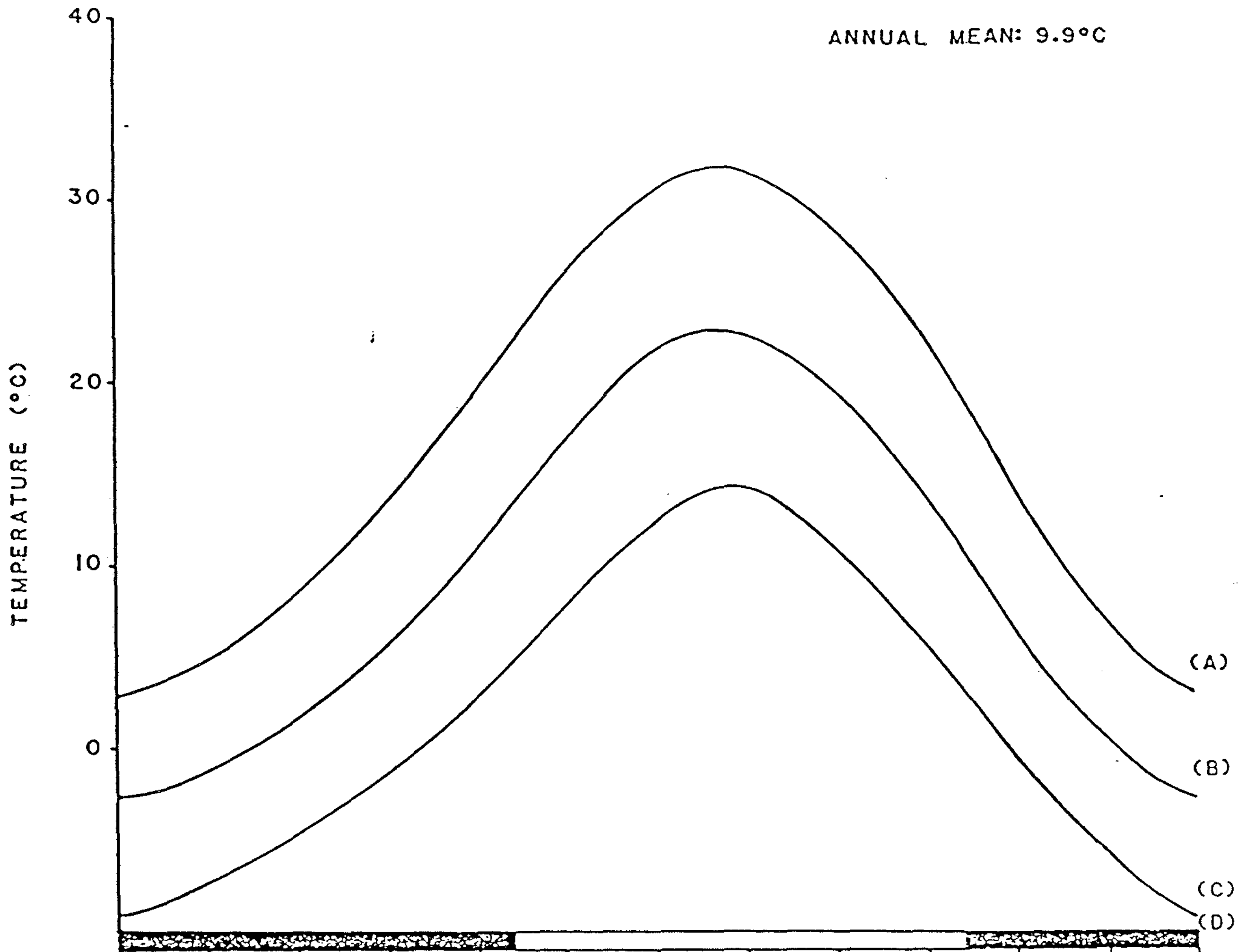
Daily Precipitation Values, Station #42073807, Blanding, Utah January, 1988 through February, 1994									
Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)	Date	Precipitation (inches)
11/16/88	0	11/16/90	0	11/16/91	0.03	11/15/92	0	11/16/93	0
11/17/88	0.02	11/17/90	0	11/17/91	0	11/16/92	0	11/17/93	0
11/18/88	0	11/18/90	0	11/18/91	0.07	11/17/92	0	11/18/93	0
11/19/88	0	11/19/90	0	11/19/91	0	11/18/92	0.01	11/19/93	0
11/20/88	0	11/20/90	0.09	11/20/91	0	11/19/92	0	11/20/93	0
11/21/88	0	11/21/90	0	11/21/91	0	11/20/92	0.12	11/21/93	0
11/22/88	0	11/22/90	0	11/22/91	0	11/21/92	0	11/22/93	0
11/23/88	0	11/23/90	0	11/23/91	0	11/22/92	0	11/23/93	0
11/24/88	0	11/24/90	0	11/24/91	0	11/23/92	0	11/24/93	0
11/25/88	0.07	11/25/90	0	11/25/91	0	11/24/92	0	11/25/93	0
11/26/88	0.11	11/26/90	0.48	11/26/91	0	11/25/92	0	11/26/93	0
11/27/88	0	11/27/90	0.01	11/27/91	0	11/26/92	0	11/27/93	0
11/28/88	0	11/28/90	0	11/28/91	0	11/27/92	0	11/28/93	0
11/29/88	0	11/29/90	0	11/29/91	0	11/28/92	0	11/29/93	0
11/30/88	0	11/30/90	0	11/30/91	0.01	11/29/92	0	11/30/93	0
12/1/88	0.03	12/1/90	0	12/1/91	0	11/30/92	0	12/1/93	0
12/2/88	0	12/2/90	0	12/2/91	0	12/1/92	0	12/2/93	0
12/3/88	0	12/3/90	0	12/3/91	0	12/2/92	0	12/3/93	0
12/4/88	0	12/4/90	0	12/4/91	0	12/3/92	0	12/4/93	0
12/5/88	0	12/5/90	0	12/5/91	0	12/4/92	0.13	12/5/93	0
12/6/88	0	12/6/90	0	12/6/91	0	12/5/92	0.81	12/6/93	0
12/7/88	0	12/7/90	0	12/7/91	0	12/6/92	0	12/7/93	0
12/8/88	0	12/8/90	0	12/8/91	0	12/7/92	-99999	12/8/93	0
12/9/88	0	12/9/90	0	12/9/91	0	12/8/92	0.28	12/9/93	0
12/10/88	0	12/10/90	0	12/10/91	0.02	12/9/92	0	12/10/93	0
12/11/88	0	12/11/90	0	12/11/91	0.26	12/10/92	0	12/11/93	0
12/12/88	0	12/12/90	0.27	12/12/91	0	12/11/92	0	12/12/93	0.07
12/13/88	0	12/13/90	0.04	12/13/91	0	12/12/92	0.5	12/13/93	0
12/14/88	0	12/14/90	0	12/14/91	0	12/13/92	0	12/14/93	0
12/15/88	0	12/15/90	0.06	12/15/91	0	12/14/92	0	12/15/93	0.07
12/16/88	0	12/16/90	0.11	12/16/91	0	12/15/92	0	12/16/93	0.18
12/17/88	0	12/17/90	0	12/17/91	0	12/16/92	0	12/17/93	0
12/18/88	0	12/18/90	0	12/18/91	0.54	12/17/92	0	12/18/93	0
12/19/88	0	12/19/90	0.06	12/19/91	0.43	12/18/92	0.2	12/19/93	0
12/20/88	0.05	12/20/90	0.36	12/20/91	0	12/19/92	0	12/20/93	0
12/21/88	0.38	12/21/90	0	12/21/91	0	12/20/92	0	12/21/93	0
12/22/88	0	12/22/90	0	12/22/91	0	12/21/92	0	12/22/93	0
12/23/88	0.2	12/23/90	0	12/23/91	0	12/22/92	0	12/23/93	0
12/24/88	0.13	12/24/90	0	12/24/91	0	12/23/92	0	12/24/93	0
12/25/88	0.09	12/25/90	0	12/25/91	0	12/24/92	0	12/25/93	0
12/26/88	0	12/26/90	0	12/26/91	0	12/25/92	0	12/26/93	0
12/27/88	0	12/27/90	0	12/27/91	0	12/26/92	0	12/27/93	0.1
12/28/88	0	12/28/90	0	12/28/91	0	12/27/92	0	12/28/93	0
12/29/88	0	12/29/90	0	12/29/91	0.05	12/28/92	0.3	12/29/93	0
12/30/88	0	12/30/90	0	12/30/91	0.11	12/29/92	0	12/30/93	0
12/31/88	0	12/31/90	0	12/31/91	0.02	12/30/92	0.07	12/31/93	0
						12/31/92	0		
Notes:	Source: Utah Climet Center, Utah State University, Logan, UT.								

Table 1 (cont.)

TABLE 2

22/34

MONTHLY MEANS AND EXTREMES OF TEMPERATURES BLANDING, UTAH



MONTH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
EXTREME MAX.	16	18	24	27	33	38	38	37	34	29	21	15
MEAN MAX.	3.8	6.9	10.9	16.3	22.8	28.7	31.9	30.2	26.0	18.8	10.2	4.5
MEAN	-2.5	0.5	3.4	8.4	14.1	19.4	23.1	21.6	17.2	10.9	3.6	-1.7
MEAN MIN.	-8.8	-5.9	-3.2	0.4	5.4	10.1	14.2	13.1	8.4	2.9	-3.2	-7.8
EXTREME MIN.	-29	-22	-15	-11	-6	-1	8	3	-5	-12	-19	-22

(A) MEAN DAILY MAXIMUM
(B) MEAN MONTHLY
(C) MEAN DAILY MINIMUM
(D) FREEZE DATES

DAMES & MOORE

PLATE 2.7-2

Appendix D

TAILINGS AND RANDOM FILL PROPERTIES

24/34

Table 3.4-1

Physical Properties of Tailings

and

Proposed Cover Materials

Material Type	Atterberg Limits LL	Atterberg Limits PI	Specific Gravity	% Passing No. 200 Sieve	Maximum Dry Density (pcf)	Optimum Moisture Content
Tailings	28	6	2.85	46	104.0	18.1
Random Fill	22	7	2.67	48	120.2	11.8
Clay	29	14	2.69	56	121.3	12.1
Clay	36	19	2.75	68	108.7	18.5

Note: Physical Soil Data from Chen and Associates (1987).

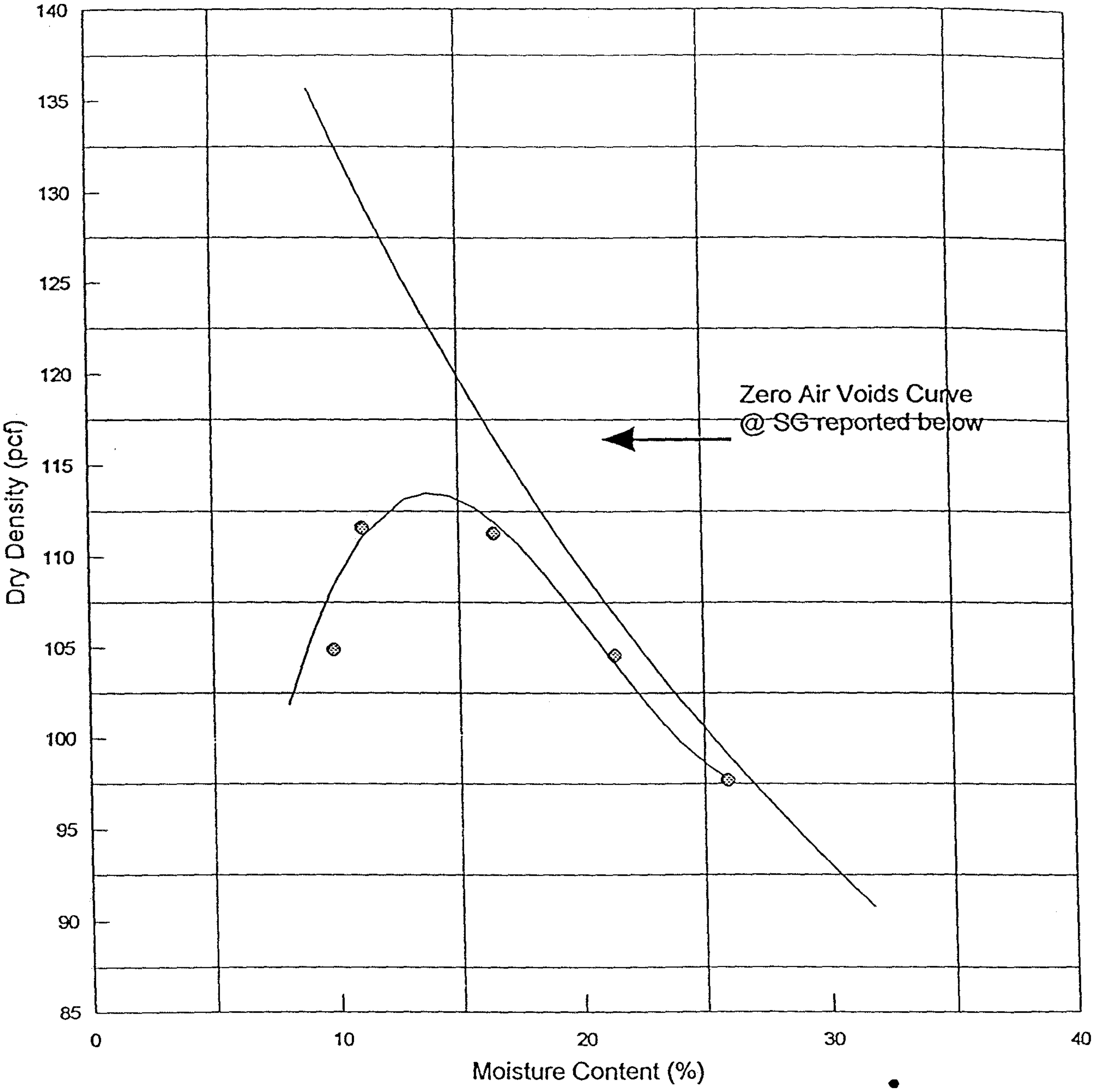
ADVANCED TERRA TESTING inc.

833 Parfet Street
Lakewood, Colorado 80215
(303) 232-8308

Proctor Compaction Test

, , UT-1

26/34



– Best Fit Curve ⊗ Actual Data

– Zero Air VoidsCurve @ SG = 2.70

CLAY

OPTIMUM MOISTURE CONTENT = 13.9 MAXIMUM DRY DENSITY = 113.5
ASTM D 1557 A, Rock correction applied? N

ADVANCED TERRA TESTING, INC.

PERMEABILITY DETERMINATION
FALLING HEAD
FIXED WALL

27/34

CLIENT Titan Environmental JOB NO. 2234-04

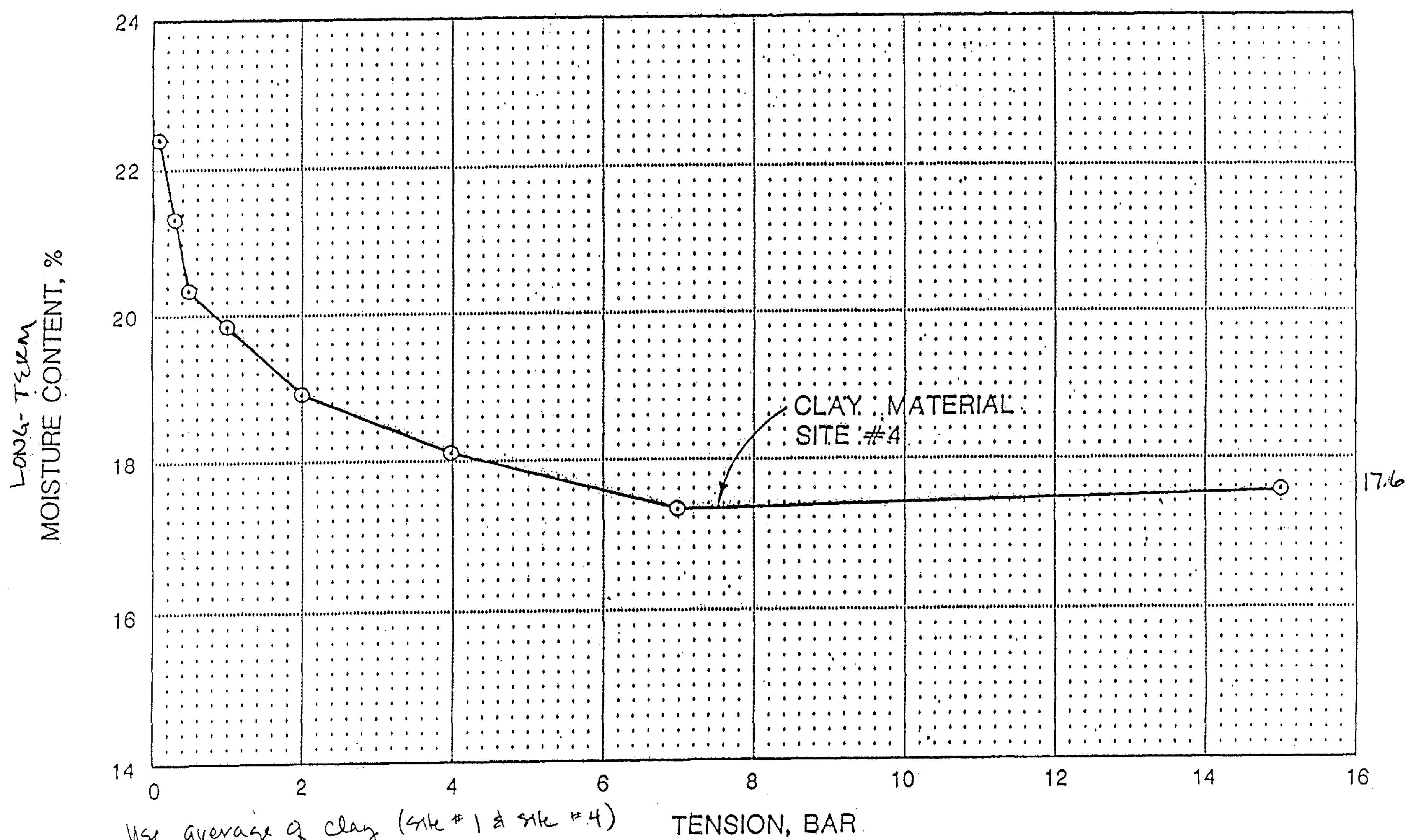
BORING NO.		SAMPLED	
DEPTH		TEST STARTED	7-28-96 CAL
SAMPLE NO.	UT-1	TEST FINISHED	8-7-96 CAL
SOIL DESCR.	Remolded 95% Mod Pt. @ OMC	SETUP NO.	1
SURCHARGE	200		

MOISTURE/DENSITY DATA	BEFORE TEST	AFTER TEST
Wt. Soil & Ring(s) (g)	386.9	404.5
Wt. Ring(s) (g)	93.0	93.0
Wt. Soil (g)	293.9	311.4
Wet Density PCF	122.3	120.5
Wt. Wet Soil & Pan (g)	302.4	319.9
Wt. Dry Soil & Pan (g)	266.2	266.2
Wt. Lost Moisture (g)	36.2	53.8
Wt. of Pan Only (g)	8.5	8.5
Wt. of Dry Soil (g)	257.7	257.7
Moisture Content %	14.1	20.9
Dry Density PCF	107.2	99.7
Max. Dry Density PCF	113.5	113.5
Percent Compaction	94.4	87.8

ELAPSED TIME (MIN)	BURETTE READING h1 (CC)	BURETTE READING h2 (CC)	PERCOLATION RATE FT/YEAR	PERCOLATION RATE CM/SEC
	0.2			
2599	10.8	10.8	0.14	1.4E-07
1427	14.2	14.2	0.09	8.4E-08
1440	16.8	16.8	0.07	6.5E-08
1440	18.6	18.6	0.05	4.6E-08
1440	20.2	20.2	0.04	4.1E-08
1440	21.6	21.6	0.04	3.7E-08
1469	23.0	23.0	0.04	3.6E-08
1440		24.4	0.04	3.7E-08 = Permeability (CLAY)

Data Entered By: NAA Date: 8-8-96
Date Checked By: [signature] Date: 8-8-96
Filename:TIFHUT1

ADVANCED TERRA TESTING, INC.



Use average of clay (site #1 & site #4) for long-term moisture content of clay

FIGURE 4.4-2
SUMMARY OF CAPILLARY MOISTURE RELATIONSHIP TEST RESULTS
WHITE MESA PROJECT

DATA FROM CHEN & ASSOCIATES;

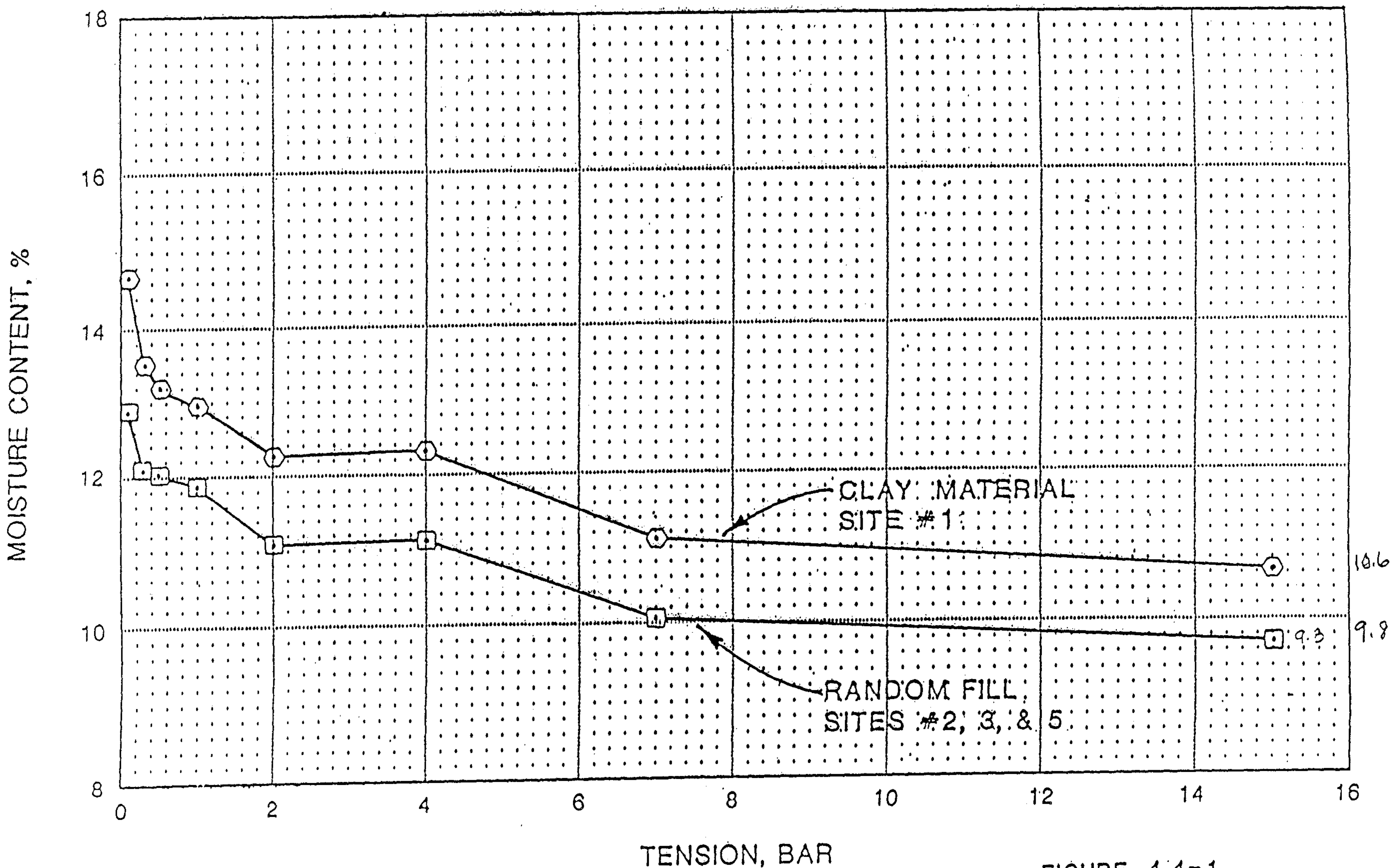


FIGURE 4.4-1
SUMMARY OF CAPILLARY MOISTURE
RELATIONSHIP TEST RESULTS
WHITE MESA PROJECT

DATA FROM CHEN & ASSOCIATES

29/34

Porosity

Porosity is calculated from the specific gravity and dry bulk density according to the following equations;

1. Dry bulk density = [(specific gravity)(density of water)]/[1 + e] (Ref: Principles & Practice of Civil Engineering, 1996). See Appendix C.
2. Porosity = [e / (1+e)] x 100 (Ref: Principles & Practice of Civil Engineering, 1996). See Appendix C.

	Max. Dry Density (lb/ft^3) (1)	Dry Bulk Density (lb/ft^3) (2)	Specific Gravity (1)	Density of Water (lb/ft^3)	"e" (3)	porosity (4)
Tailings	104.0	93.6	2.85	62.4	0.90	47%
Clay (5)	115.0	103.5	2.72	62.4	0.64	39%
Random fill	120.2	108.2	2.67	62.4	0.54	35%

Notes:
1. Physical soil data from Chen and Associates (1987) included in Appendix B.
2. Bulk dry density is 90% of the ASTM Proctor maximum dry density for all materials.
3. Calculated using Equation 1 above.
4. Calculated using Equation 2 above.
5. Clay physical data are average values from site #1 and site #4 clay stockpiles as given by Umetco Minerals Corp. 1988.

1/5" x 1/5"

Determination of Parameters (Contd.)

Permeability; No permeability data is available for tailings.

Clay material – The permeability of the clay material is an average for all clay materials near the site as given by Chen + Associates (1978) as "Laboratory Permeability Test Results."

The permeability value is an average of the following values;

(Assume permeabilities for site #1 + site #4 clays are similar)

Permeability;		
	8.2×10^{-8} cm/s	Chen + Associates (7/18/78)
	6.6×10^{-8}	
	1.2×10^{-8}	
	4.0×10^{-8}	
	1.6×10^{-8}	
	2.3×10^{-8}	
	3.2×10^{-8}	
	7.8×10^{-7}	(1/25/79)
	1.5×10^{-6}	
	2.1×10^{-7}	
	4.2×10^{-7}	
	1.2×10^{-7}	
	5.0×10^{-7}	
	Ave. = 2.92×10^{-7}	

Random fill – The permeability of the random fill material is an average for all sand and silt material as given by Chen + Associates (1978, 79) as "Laboratory Permeability Test Results."

The permeability is an average of the following values;

Permeability;		
	5.5×10^{-7}	Chen + Ass. (7/18/78)
	3.4×10^{-8}	
	6.1×10^{-7}	
	4.3×10^{-6}	(1/23/94)
	3.7×10^{-7}	
	5.8×10^{-7}	
	1.1×10^{-7}	
	5.4×10^{-7}	

Permeability (Random fill) = Ave. = 8.87×10^{-7} cm/s

TABLE I

SUMMARY OF LABORATORY TEST RESULTS

Test Hole	Depth (Ft.)	NATURAL Moisture Content (%)	NATURAL Dry Density (pcf)	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	ATTERBERG LIMITS Liquid Limit (%)	ATTERBERG LIMITS Plasticity Index (%)	GRADATION ANALYSIS Maximum Size	GRADATION ANALYSIS Passing #200 (%)	GRADATION ANALYSIS Less than 2 μ (%)	REMOLDED Dry Density (pcf)	REMOLDED Moisture Content (%)	PERMEABILITY ft./yr.	PERMEABILITY cm./sec.	Specific Gravity	Soil Type
2	0-5			117.5	10.8	20	3	#16	58	19	111.6	16.4	0.57	5.5×10^{-7}		Sandy Silt
3	7-8	7.2				21	6	#16	62							Sandy Clayey Silt
5	7½-10			104.1	18.5	33	8	3/4 In.	56	12	102.1	22.0	0.085	8.2×10^{-8}	2.65	Calcareou. Silty Clay
6	1-2	10.3				25	7	#16	77							Sandy Clay Silt.
6	8½-9	6.1				27	8	#4	70							Sandy Clay
8	5-5½	13.1					NP	3/4 In.	62							Calcareous Sandy Silt
9	0-1	8.1					NP	#16	53							Sand - Silt
10	4-6½					24	10	#4	73							Sandy Clay
11	5½-6½	14.0				26	6	#16	65							Siltstone– Claystone
12	2-5			101.0	20.6	53	35	#16	88	59	95.0	18.3	0.068	6.6×10^{-8}	2.67	Weathered Claystone
13	7-8	13.1				39	13	#8	84							Calcareous Silt Clay
14	1-2	19.3				40	21	#4	89							Weathered Claystone
15	1½-4½			106.8	19.0	26	8	3/8 In.	65	27	103.4	18.0	0.012	1.2×10^{-8}	2.64	Mod. Calcareous Sandy Clay
17	2-3	11.4				19	4	#8	59							Sandy Silt
19	0-3			117.5	12.8	23	6	#16	70		109.9	12.4	0.035	3.4×10^{-8}		Sandy Clayey Silt
22	1-2	13.2				26	10	#4	73							Sandy Clay
23	1-3					48	24	#30	87							Weathered Claystone
23	6-8					61	30	#30	96							Claystone
25	1-3½	13.3				26	9	#4	57							Sandy Clay
26	4½-5	15.3				41	20	#4	91							Weathered Claystone
28	0-2	12.7				28	10	3/8 In.	72							Sandy Clay
29	2-3	8.5				19	2	#16	59							Sandy Silt
32	8-8½	5.6				23	6	#30	73							Sandy Clayey Silt
37	0-4			118.8	11.5	23	5	#8	72		110.5	11.5	0.63	6.1×10^{-7}		Sandy Clayey Silt
38	5-7			111.0	16.7	29	14	3/8 In.	69		102.4	17.9	0.041	4.0×10^{-8}		Sandy Clay
40	4-5½			110.0	16.2	26	9	#8	64	27	106.4	16.4	0.017	1.6×10^{-8}	2.65	Sandy Clay

TABLE I

SUMMARY OF LABORATORY TEST RESULTS

Test Hole	Depth (Ft.)	NATURAL Moisture Content (%)	NATURAL Dry Density (pcf)	Maximum Dry Density (pcf)	Optimum Moisture Content (%)	ATTERBERG LIMITS Liquid Limit (%)	ATTERBERG LIMITS Plasticity Index (%)	GRADATION ANALYSIS Maximum Size	GRADATION ANALYSIS Passing #200 (%)	GRADATION ANALYSIS Less than 2 μ (%)	REMOLDED Dry Density (pcf)	REMOLDED Moisture Content (%)	PERMEABILITY ft./yr.	PERMEABILITY cm./sec.	Specific Gravity	Soil Type
40	9-9½	6.8				22	8	3/8 in.	60							Sandy Clay
42	13½-14½	7.6				26	10	3/8 in.	73							Sandy Clay
43	11-12	12.1				41	22	#4	86							Claystor
43	13½-16½			110.0	16.9	40	24	3/8 in.	85	44	104.1	15.8	0.024	2.3×10^{-8}	2.62	Clayston
44	6½-7	7.5				30	11	3/8 in.	79							Calcareous Sandy Clay
46	0-2	12.3				22	6	#16	76							Sandy Clayey Silt
48	5-5½					30	9	3/8 in.	65							Sandy Clay
49	5-7			110.7	15.6	25	9	#16	71		105.2	13.9	0.33	3.2×10^{-8}		Sandy Clay
49	14-15					28	5	#8	55							Calcareous Sandy Silt
54	0-2	12.1				23	9	#8	64							Sandy Clay
55	5-5½	7.8				28	14	#30	71							Sandy Clay
55	9½-10½					28	13	#4	71							Sandy Clay
58	5½-6	12.5				35	11	#4	75							Sandy, Silty Clay
61	0-1	11.5				21	4	#16	75							Sandy Silt
62	11-11½	8.1					NP	1 in.	34							Calcareous Sand & …
63	4-6					30	14	#8	68							Sandy C…
65	1-2	9.0					NP	#16	44							Silty S…
68	7½-8	8.6				28	13	#8	67							Sandy Clay
70	3½-4½	16.4				27	4	1½ in.	46							Calcareous Sand & Silt
72	0-2	12.2				22	8	#16	59							Sandy Clay
75	10-11	12.4				41	25	#4	75							Weathered Claystone
75	12-14					45	22	#16	93							Claystone

416,406

33/34

TABLE II

LABORATORY PERMEABILITY TEST RESULTS

Sample	Soil Type	Compaction: Dry Density (pcf)	Compaction: Moisture Content (%)	Compaction: % of ASTM D698	Surcharge Pressure (psf)	Permeability (Ft/Yr)	Permeability (Cm/S
TH 2 @ 0'-5'	Sandy Silt	111.6	16.4	95	500	0.57	5.5[illegible]
TH 5 @ 7½'-10'	Calcareous Silty Clay	102.1	22.0	101	500	0.085	8.2[illegible]
TH 12 @ 2'-5'	Weathered Claystone	95.0	18.3	94	500	0.068	6.6x10[illegible]
TH 15 @ 1½'-4½'	Calcareous Sandy Clay	103.4	18.0	97	500	0.012	1.2x10[illegible]
TH 19 @ 0'-3'	Sandy, Clayey Silt	109.9	12.4	94	500	0.035	3.4x10[illegible]
TH 37 @ 0'-4'	Sandy, Clayey Silt	110.5	11.5	93	500	0.63	6.1x10[illegible]
TH 38 @ 5'-7'	Sandy Clay	102.4	17.9	92	500	0.041	4.0x10[illegible]
TH 40 @ 4'-5½'	Sandy Clay	106.4	16.4	97	500	0.017	1.6x10[illegible]
TH 43 @ 13½-16½'	Claystone	104.1	15.8	95	500	0.024	2.3x10[illegible]
TH 49 @ 5'-7'	Sandy Clay	105.2	13.9	95	500	0.33	3.2[illegible]

APPENDIX E

Freeze/Thaw Evaluation

Purpose: To determine if freeze/thaw conditions will impact the performance of the White Mesa uranium mill tailings cover. This calculation brief predicts the depth of frost which may be anticipated at the mill site. Only frost depth is evaluated since this would have the greatest impact on cover integrity (i.e. increasing permeability or damage by frost heave).

Method: A digital computer program of the modified Berggren equation for calculating the depth of freeze or thaw in a multi-layered soil system was used for purposes presented in this calculation. This method, used for determining the frost depth, is considered adequate for Uranium Mill Tailings Remedial Action (UMTRA) Projects by the U.S. Department of Energy for the following reasons:

- It calculates depth of frost based on a zero degrees Celsius isotherm, whereas the frozen front occurs some distance above this line.
- Extrapolation of current weather records beyond 200 years is not reliable.
- Extreme changes in temperatures for the 1,000 year design life are not anticipated based on geomorphic evidence.

Parameters for the cover materials based on accepted methods and existing database values previously collected, were input into the computer modeling program to determine the depth of frost penetration. A cover thickness of 2 feet random fill over 1 foot of compacted clay (as determined by HELP and RADON computer modeling) was used.

Assumptions: The model assumes:

- One-dimensional heat flow with the entire soil mass at its mean annual temperature prior to the start of the freezing season.
- At the start of the freezing season, the surface temperature changes suddenly from the mean annual temperature to a temperature below freezing and remains at this temperature throughout the entire freezing season.
- The effect of latent heat is considered as a heat sink at the moving frost line.
- Soil freezes at a temperature of 32 degrees Fahrenheit.

Results: The total frost penetration depth is less than 6.8 inches. Therefore, the 2-foot layer of random fill will provide adequate protection to the underlying 1-foot clay layer. See Appendix A for computer modeling results.

Parameters: The computer program requires input of the following parameters for the soil cover layers:

- freezing index (degree);
- length of season (days);
- mean annual temperature (degrees Fahrenheit);
- n-factor;
- layer thickness' (inches);
- water content (percent);
- dry unit weight (lbs/cubic foot);
- heat capacity (Btu/cubic foot-deg F);
- thermal conductivity (Btu/foot-hour-deg F), and;
- latent heat of fusion (Btu/cubic foot).

Freezing Index/Length of Season/Mean Annual Temperature

Default values from Grand Junction, Colorado were used for the freezing index and length of season. Grand Junction, Colorado was used for default parameters since it is similar in elevation and climate to Blanding Utah. An actual mean annual temperature for Blanding Utah from Dames & Moore (1978) was used for modeling purposes (see Appendix B).

N-factor

A default n-factor of 0.70 for sand and gravel surface type was used as per recommended in the freeze/thaw model guidelines (Aitken and Berg, 1968).

Soil type

Soil type was considered to be fine grained soil for both cover layers. Soil type number is 5.

Layer thickness'

The thickness of the cover materials were determined by infiltration and radon flux modeling programs to be 2 feet of random fill over 1 foot of clay. For this calculation, a single 36-inch layer was used. This was used because the random fill and clay soil have very similar properties.

Moisture Content

Optimum moisture content from Chen and Associates (1987) and Advanced Terra Testing (1996) was used for the random fill and the clay (UT-1) layer respectively. This data is included in Appendix B.

Optimum moisture content:

random fill	=11.8%
clay	=13.9%

A weighted averaged moisture content of 12.5 percent was used for this analysis.

Soil Density

Soil dry density was determined from Chen and Associates (1987) for random fill and Advanced Terra Testing (1996) for clay. The maximum dry density for the random fill was measured to be 120.2 pounds per cubic foot (pcf) and the maximum dry density for the clay was measured to be 113.5 pcf. Assuming the soil will be compacted to 95 percent of the maximum density, the weighted average bulk soil density would be 112 pcf.

Heat Capacity

Based on the nomographs presented in Aitken and Berg (1968) and included herein as Figure 1, using an average soil density of 112 pcf and an average moisture content of 12.5 percent yields a heat capacity of 30 Btu/ft^3 ° F.

Thermal Conductivity

Thermal conductivity of the soil cover was assumed to be similar to that for a dry sand. The thermal conductivity of a dry sand is reported to be 0.19 Btu/ hr. ft °F (Perry, Robert H. et al., 1984) (see Table 1).

Latent Heat

Based on the nomographs presented in Aitken and Berg (1968) and included herein as Figure 1, using an average soil density of 112 pcf and an average moisture content of 12.5 percent yields a Latent Heat of 2000 Btu/ ft^3 .

References:

Advanced Terra Testing, 1996. Physical soil data, White Mesa Project, Blanding Utah, July 25, 1996.

Aitken, George W. and Berg, Richard L., 1968, "Digital Solution of Modified Berggren Equation to Calculate Depths of Freeze or Thaw in Multilayered Systems", October, 1968.

Chen and Associates, 1987. Physical soil data, White Mesa Project Blanding Utah.

Dames & Moore, 1978. "Environmental Report, White Mesa Uranium Project, San Juan County, Utah, January 20, 1978, revised May 15, 1978.

Perry, Robert H. et al., 1984. "Perry's Chemical Engineers' Handbook, Sixth Edition", McGraw Hill Book Company, 1984.

U.S. Department of Energy, 1988, "Effect of Freezing and Thawing on UMTRA Covers" Albuquerque, New Mexico, October 1988.

TABLE 1

5/18

~~TABLE 3-320~~ **Thermal Conductivities of Some Building and Insulating Materials***

k = Btu/(h·ft²)(°F/ft)

Material	Apparent density ρ, lb./cu. ft. at room temperature	t, °C.	k
Aerogel, silica, opacified	8.5	120	0.013
		290	.026
Asbestos-cement boards	120	20	.43
Asbestos sheets	55.5	51	.096
Asbestos slate	112	0	.087
	112	60	.114
Asbestos	29.3	−200	.043
	29.3	0	.090
	36	0	.087
	36	100	.111
	36	200	.120
	36	400	.129
	43.5	−200	.090
	43.5	0	.135
Aluminum foil (7 air spaces per 2.5 in.)	0.2	38	.025
		177	.038
Ashes, wood	......	0–100	.041
Asphalt	132	20	.43
Boiler scale (Note 1)			
Bricks:			
Alumina (92–99% Al_2O_3 by wt.) fused	......	427	1.8
Alumina (64–65% Al_2O_3 by wt.)	......	1315	2.7
(See also Bricks, fire clay)	115	800	0.62
	115	1100	.63
Building brick work	......	20	.4
Carbon	96.7	....	3.0
Chrome brick (32% Cr_2O_3 by wt.)	200	200	.67
	200	650	.85
	200	1315	1.0
Diatomaceous earth, natural, across strata (Note 2)	27.7	204	0.051
	27.7	871	.077
Diatomaceous, natural, parallel to strata (Note 2)	27.7	204	.081
	27.7	871	.106
Diatomaceous earth, molded and fired (Note 2)	38	204	.14
	38	871	.18
Diatomaceous earth and clay, molded and fired (Note 2)	42.3	204	.14
	42.3	871	.19
Diatomaceous earth, high burn, large pores (Note 3)	37	200	.13
	37	1000	.34
Fire clay (Missouri)	......	200	.58
		600	.85
		1000	.95
		1400	1.02
Kaolin insulating brick (Note 3)	27	500	0.15
	27	1150	.26
Kaolin insulating firebrick (Note 4)	19	200	.050
	19	760	.113
Magnesite (86.8% MgO, 6.3% Fe_2O_3, 3% CaO, 2.6% SiO_2 by wt.)	158	204	2.2
	158	650	1.6
	158	1200	1.1
Silicon carbide brick, recrystallized (Note 3)	129	600	10.7
	129	800	9.2
	129	1000	8.0
	129	1200	7.0
	129	1400	6.3
Calcium carbonate, natural	162	30	1.3
White marble	......	....	1.7
Chalk	96	....	0.4
Calcium sulfate ($4H_2O$), artificial	84.6	40	.22
plaster (artificial)	132	75	.43
(building)	77.9	25	.25
Cambric (varnished)	......	38	.091
Carbon, gas	......	0–100	2.0
Carbon stock	94	−184	0.55
		0	3.6
Cardboard, corrugated	......	....	0.037
Celluloid	87.3	30	.12
Charcoal flakes	11.9	80	.043
	15	80	.051
Clinker (granular)	......	0–700	.27
Coke, petroleum	......	100	3.4
		500	2.9
Coke, petroleum (20–100 mesh)	62	400	0.55
Coke (powdered)	......	0–100	.11
Concrete (cinder)	......	....	.20
(stone)	......	....	.54
(1:4 dry)	......	....	.44

Material	Apparent density ρ, lb./cu. ft. at room temperature	t, °C.	k
Cotton wool	5	30	0.024
Cork board	10	30	.025
Cork (regranulated)	8.1	30	.026
(ground)	9.4	30	.025
Diatomaceous earth powder, coarse (Note 2)	20.0	38	.036
	20.0	871	.082
fine (Note 2)	17.2	204	.040
	17.2	871	.074
molded pipe covering (Note 2)	26.0	204	.051
	26.0	871	.088
4 vol. calcined earth and 1 vol. cement, poured and fired (Note 2)	61.8	204	.16
	61.8	871	.23
Dolomite	167	50	1.0
Ebonite	......	....	0.10
Enamel, silicate	38	....	0.5–0.75
Felt, wool	20.6	30	0.03
Fiber insulating board	14.8	21	.028
Fiber, red	80.5	20	.27
(with binder, baked)	......	20–97	.097
Gas carbon	......	0–100	2.0
Glass	......	....	0.2–0.73
Borosilicate type	139	30–75	0.63
Window glass	......	....	0.3–0.61
Soda glass	......	....	0.3–0.44
Granite	......	....	1.0–2.3
Graphite, longitudinal	......	20	95.
powdered, through 100 mesh	30	40	0.104
Gypsum (molded and dry)	78	20	.25
Hair felt (perpendicular to fibers)	17	30	.021
Ice	57.5	0	1.3
Infusorial earth, see diatomaceous earth			
Kapok	0.88	20	0.020
Lampblack	10	40	.038
Lava	......	....	.49
Leather, sole	62.4	....	.092
Limestone (15.3 vol. % H_2O)	103	24	.54
Linen	......	30	.06
Magnesia (powdered)	49.7	47	.35
Magnesia (light carbonate)	13	21	0.034
Magnesium oxide (compressed)	49.9	20	.32
Marble	......	....	1.2–1.7
Mica (perpendicular to planes)	......	50	0.25
Mill shavings	......	....	0.033–0.05
Mineral wool	9.4	30	0.0225
	19.7	30	.024
Paper	......	....	.075
Paraffin wax	......	0	.14
Petroleum coke	......	100	3.4
		500	2.9
Porcelain	......	200	0.88
Portland cement, see concrete	......	90	.17
Pumice stone	......	21–66	.14
Pyroxylin plastics	......	....	.075
Rubber (hard)	74.8	0	.087
(para)	......	21	.109
(soft)	......	21	0.075–0.092
Sand (dry)	94.6	20	0.19
Sandstone	140	40	1.06
Sawdust	12	21	0.03
Scale (Note 1)			
Silk	6.3	....	.026
varnished	......	38	.096
Slag, blast furnace	......	24–127	.064
Slag wool	12	30	.022
Slate	......	94	.86
Snow	34.7	0	.27
Sulfur (monoclinic)	......	100	0.09–0.097
(rhombic)	......	21	0.16
Wall board, insulating type	14.8	21	.028
Wall board, stiff paste board	43	30	.04
Wood shavings	8.8	30	.034
Wood (across grain):			
Balsa	7–8	30	0.025–0.03
Oak	51.5	15	0.12
Maple	44.7	50	.11
Pine, white	34.0	15	.087
Teak	40.0	15	.10
White fir	28.1	60	.062
Wood (parallel to grain):			
Pine	34.4	21	.20
Wool, animal	6.9	30	.021

* Marks, "Mechanical Engineers' Handbook," 4th ed., McGraw-Hill, New York, 1941. "International Critical Tables," McGraw-Hill, 1929, and other sources. For additional data, see pp. 458–459.

Note 1: B. Kamp [*Z. tech. Physik*, 12, 30 (1931)] shows the effect of increased porosity in decreasing thermal conductivity of boiler scale. Partridge [University of Michigan, *Eng. Research Bull.* 15, 1930] has published a 170-page treatise on Formation and Properties of Boiler Scale.

Note 2: Townshend and Williams, *Chem. & Met.*, 39, 219 (1932).

Note 3: Norton, "Refractories," 2d ed., McGraw-Hill, New York, 1942.

Note 4: Norton, private communication.

REF: PERRY'S CHEMICAL ENGINEERS' HANDBOOK, 1984, 6TH EDITION.

TAM
9/11/96

FIGURE 1

6/18

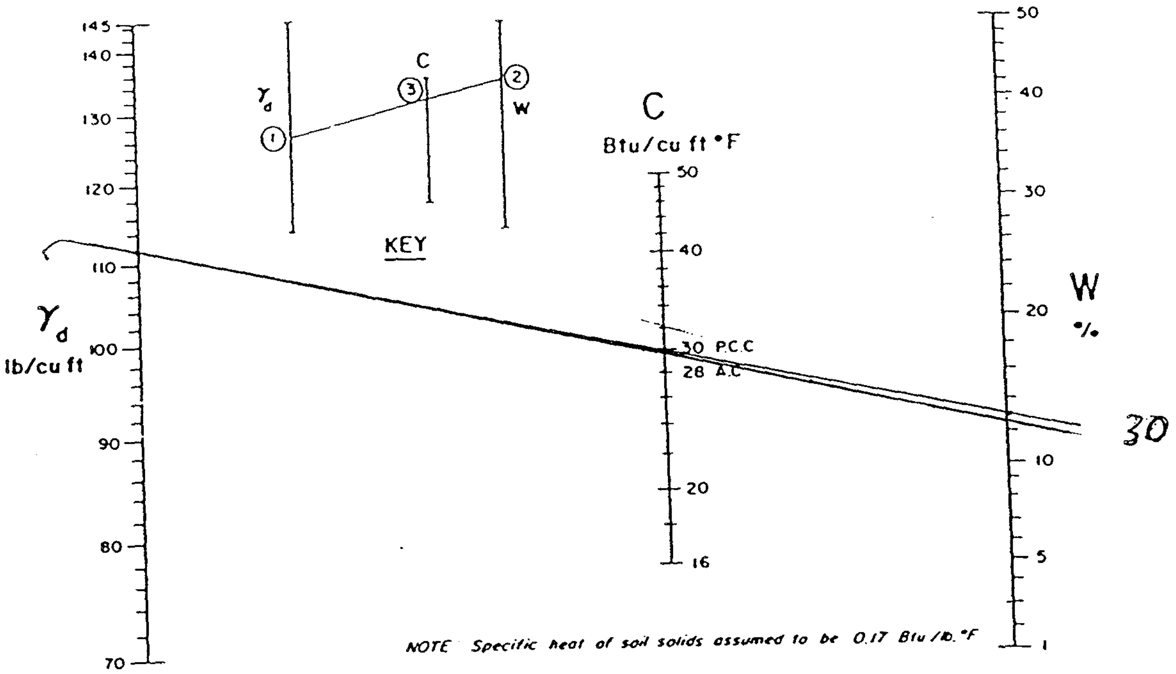


Figure 8. Average volumetric heat capacity for soils (after Aldrich and Paynter, 1953).

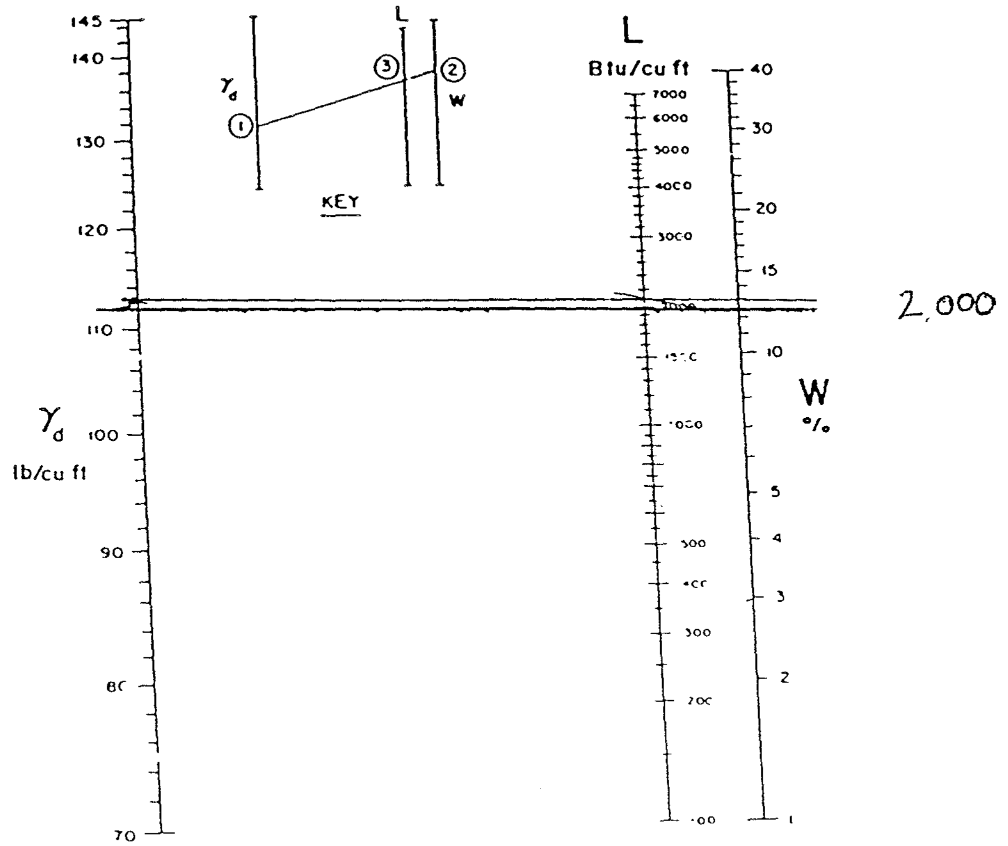


Figure 9. Volumetric latent heat for soils (after Aldrich and Paynter, 1953).

TAM
8/9/96

Appendix A

WEATHER STATIONS in Colorado:

Station Location	Design Freezing Index (°F days)	Mean Annual Temp. (°F)	Length of Freezing Season (days)
1 = Alamosa	2274	41.3	159
2 = Buckley ANGB	577	50.3	88
3 = Colorado Springs	633	48.7	67
4 = Denver	629	50.3	71
5 = Grand Junction	1101	52.6	86
6 = Pueblo	676	52.3	65

Enter the number representing the data you want:
(0 to input your own data):

TAM
9/11/94

9/18

LOCATION and WEATHER DATA

Input weather data for your location in Colorado:

DESIGN AIR FREEZING Index (F-Days): 1101

MEAN ANNUAL TEMPERATURE (F): 49.8

LENGTH of FREEZING SEASON (Days): 86

TAM
9/11/96

10/18

CHOOSE an APPROPRIATE N-FACTOR

Surface Type	N-Factor * (Freezing)
1 = Portland Cement (snow-free)	0.75
2 = Asphalt (snow-free)	0.70
3 = Snow	1.00
4 = Sand and Gravel (snow-free)	0.70
5 = Turf (snow-free)	0.50

0 = To input your own N-Factor

Enter your option: 4

* N-Factor varies with lattitude, wind speed, cloud cover, and other climatic conditions.

TAM
9/11/96

11/18

INFORMATION for LAYER 1:

Choose the appropriate soil type for this layer --

1 = Portland Cement stabilized layer
2 = Asphalt stabilized layer
3 = Snow
4 = Course-grained soil
5 = Fine-grained soil
6 = Insulating layer
7 = Organic soil

Enter your option: 5

TAM
9/11/96

LAYER PARAMETERS

Parameters for LAYER 1, Fine-grained		Default Values	Values Used
Layer Thickness (inches)		12.0	36.0
Moisture Content (% dry weight)		17.0	12.5
Dry Unit Weight (lbs/cubic foot)		122.0	112.0
Heat Capacity (Btu/cubic foot °F)	*	29.5	30.0
Thermal Conductivity (Btu/foot hour °F)	*	0.90	0.19
Latent Heat of Fusion (Btu/cubic foot)	*	2016.0	2000

* recalculated based upon new MOISTURE CONTENT/WEIGHT value(s).

...<return> for Default Values...

TAM
9/11/94

Summary: MODIFIED BERGGREN SOLUTION

Design Freezing Index (AIR) = 1101 F-days
Design Freezing Index (SURFACE) = 771 F-days
Mean Annual Temperature = 49.8 °F
Length of Freezing Season = 86 Days

LAYER #: Type	LAYER THICKNESS (inches)	FREEZING INDEX DISTRIBUTION Each Layer	Accum	Berggren
1: Fine-grained	< 6.8	145	←	Calculations could not converge Surface DFI

End of Frost Penetration

TOTAL FROST PENETRATION = 6.8 inches

Do you want a hard copy of this data (Y or default N)?

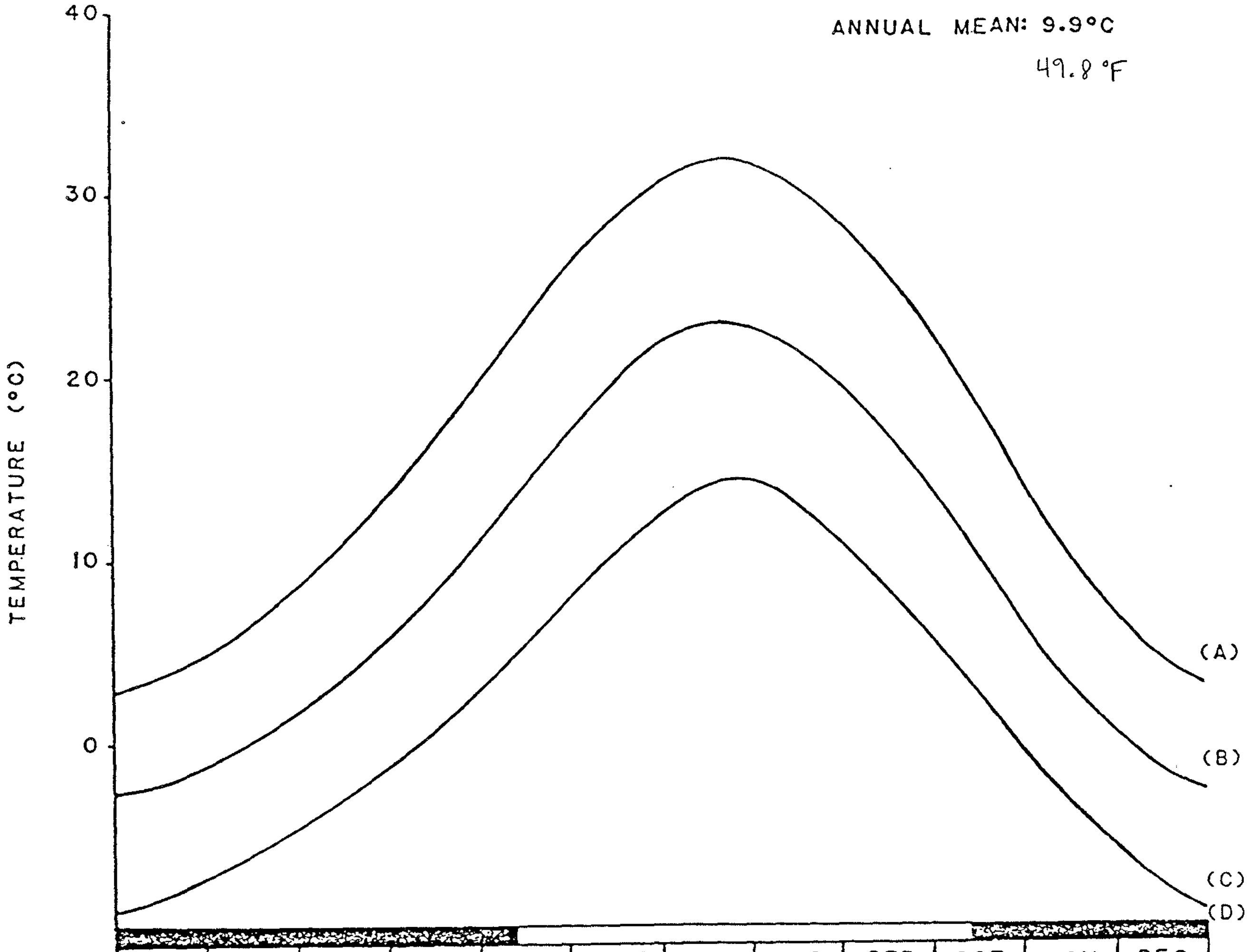
TAM
9/11/96

Appendix B

T

15/18

MONTHLY MEANS AND EXTREMES OF TEMPERATURES BLANDING, UTAH



MONTH	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC
EXTREME MAX.	16	18	24	27	33	38	38	37	34	29	21	15
MEAN MAX.	3.8	6.9	10.9	16.3	22.8	28.7	31.9	30.2	26.0	18.8	10.2	4.5
MEAN	-2.5	0.5	3.4	8.4	14.1	19.4	23.1	21.6	17.2	10.9	3.6	-1.7
MEAN MIN.	-8.8	-5.9	-3.2	0.4	5.4	10.1	14.2	13.1	8.4	2.9	-3.2	-7.8
EXTREME MIN.	-29	-22	-15	-11	-6	-1	8	3	-5	-12	-19	-22

(A) MEAN DAILY MAXIMUM
(B) MEAN MONTHLY
(C) MEAN DAILY MINIMUM
(D) FREEZE DATES

DAMES & MOORE

PLATE 2.7-2

16/18

TAILINGS AND RANDOM FILL PROPERTIES

Table 3.4-1

Physical Properties of Tailings

and

Proposed Cover Materials

Material Type	Atterberg Limits LL	Atterberg Limits PI	Specific Gravity	% Passing No. 200 Sieve	Maximum Dry Density (pcf)	Optimum Moisture Content
Tailings	28	6	2.85	46	104.0	18.1
Random Fill	22	7	2.67	48	120.2	11.8
Clay	29	14	2.69	56	121.3	12.1
Clay	36	19	2.75	68	108.7	18.5

Note: Physical Soil Data from Chen and Associates (1987).

17/18

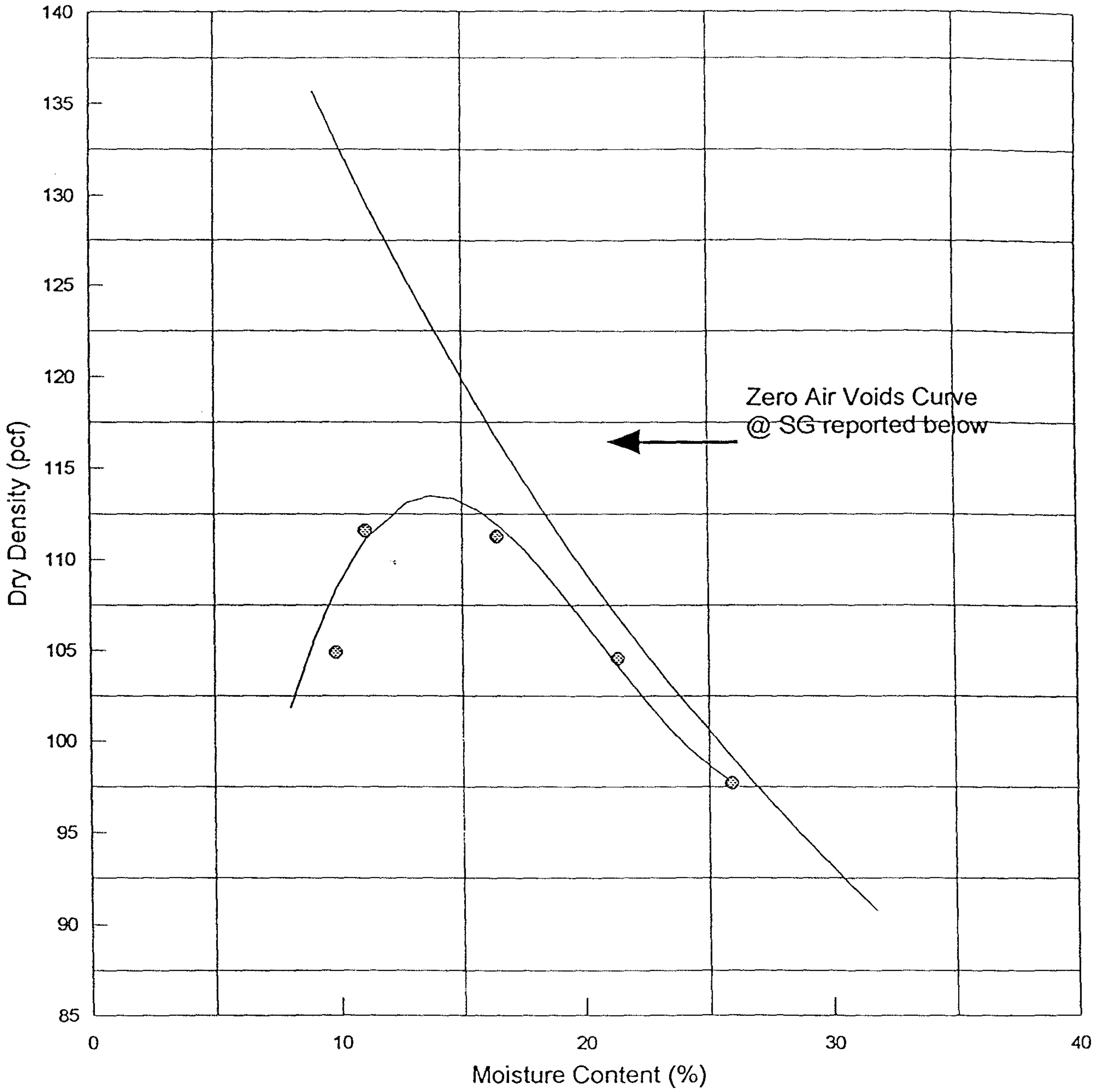
ADVANCED TERRA TESTING inc

833 Parfet Street
Lakewood, Colorado 80215
(303) 232-8308

Proctor Compaction Test

, , UT-1

18/18



- Best Fit Curve
- Actual Data
- Zero Air VoidsCurve @ SG = 2.70

OPTIMUM MOISTURE CONTENT = 13.9 MAXIMUM DRY DENSITY = 113.5
ASTM D 1557 A, Rock correction applied? N

ADVANCED TERRA TESTING, INC.

APPENDIX F

Erosion Protection

PURPOSE:

Design of Erosion Protection layer of Riprap for the Cover of Uranium Tailings

An erosion protection layer of rock riprap is required to protect the soil cover for the uranium mill tailings at Blanding, Utah. The cover is supposed to have a design life of 1000 years according to requirements set by U.S. Nuclear Regulatory Commission [Ref: "Final Staff Technical Position - Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites", 1990; U.S. Nuclear Regulatory Commission (U.S.N.R.C.)]. Hence the erosion protection layer should be designed accordingly. A design for the stone size and overall riprap thickness required for erosion protection is provided in this document.

METHODOLOGY:

The design for rock riprap for protection of top and side slopes of the cover is based on the guidelines provided by the following documents:

a) "Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments" (NUREG/CR-4620), 1986; U.S. Nuclear Regulatory Commission

b) "Final Staff Technical Position - Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites", 1990; U.S. Nuclear Regulatory Commission (U.S.N.R.C.)

c) "Development of Riprap Design Criteria by Riprap Testing in Flumes"(NUREG/CR-4651), 1987; U.S. Nuclear Regulatory Commission

The top of the cover and the side slopes will be designed separately as the side slopes are much steeper than the top of the cover. Overland flow calculations will be determined based on the guidelines set by Nuclear Regulatory Commission and the site data. The size of the riprap placed on top of the tailings cover will be determined using the Safety Factor method (NUREG/CR-4651), while the Stephenson method (NUREG/CR-4651) will be applied for those placed along the side slopes.

A: Overland Flow Calculations

The methods for overland flow calculations are same for top and side slopes of the cover. The results have been tabulated under Table 1A and 2A respectively. The formulas, methodologies and equations used for overland flow calculations are discussed in this part of the document. The calculations are based on unit width of drainage area.

Average Slope 'S' and Length of drainage basin 'L': Figure 1 shows the direction of drainage for cells 2, 3 & 4. Table 1A calculates the flow parameters by varying slopes and slope lengths of cells 2, 3 & 4. Runoff and flow calculations have been provided for slopes ranging from 0.001 to 0.008 for cells 2 and 4 and from 0.001 to 0.005 for cell 3. As the slopes are very gentle, for each cell the drainage length varies negligibly and hence has been considered constant for calculation purpose. The drainage lengths have been measured from the site map. For erosion protection design of the side slopes, a side slope of 5H:1V and the maximum value of drainage lengths for cells 2, 3 & 4 have been considered (Table 2A).

Probable Maximum Precipitation (PMP): The 1-hour local storm PMP for White Mesa is 7.76 inches (data from NOAA, 1977).

Time of Concentration of Rainfall, T_c:

$$T_c = 0.00013\frac{L^{0.77}}{S^{0.385}}\text{hours} = 0.00013\frac{L^{0.77}}{S^{0.385}} \times 60\,\text{mins}$$ (Ref: Equation 4.44 in NUREG/CR-4620)

where, S = average slope of drainage basin and L = length of drainage basin in feet
The percentage of 1-hour precipitation is obtained by interpolating from Table 2.1 of NUREG/CR-4620. The minimum value of T_c used in this table is 2.5 minutes.

% PMP: The percentage for 1-hour precipitation (PMP) is obtained by interpolating from table 2.1 of NUREG/CR-4620.

Rainfall Depth:
Precipitation Amount (inches) = % PMP × PMP = % of 1-hour precipitation × PMP (Ref: Eqn. 2.1, NUREG/CR-4620).

Precipitation intensity, 'i':
Precipitation intensity in inches/hour can be computed as (Ref: Eqn. 2.2, NUREG/CR-4620):
i = rainfall depth (inches) × [60 / {rainfall duration T_c (minute)}]

Runoff Coefficient, C: Runoff coefficient depends on climatic conditions, the type of terrain, permeability, and storage potential of the basin. Runoff Coefficient has been assumed to be 0.8 for the top of cover and the side slopes (Ref: Appendix D, section 2.4 (Example) in "Final Staff Technical Position", U.S.N.R.C.).

Unit Area, A: Area of 1-ft wide drainage basin
A = Length of drainage basin (ft.) × width (ft.) = L × 1 sq. ft. = [L×1/(43560)] Acres

Peak discharge per unit width for the drainage basin, q:
By Rational method, q = CiA, where C, i & A have their usual meanings [q in cu. ft./sec (cfs), i in inches/hour and A in acres] (Ref: Eqns. 4.42 and 4.43, NUREG/CR-4620).

Flow Concentration Factor:
From section 4.9 of NUREG/CR-4620, "...it is reasonable to assume that values between 2 and 3 are attainable with only a slight evolutionary change in cover." Thus, a flow concentration factor of 3 and 2 have been assumed for top and side slopes respectively (as the top of cover is flatter than the side slopes, it has been assumed that concentration of flow will be higher on the top than along the side slopes).

Concentrated discharge per unit width for the drainage basin, q_c:
q_c (cu. ft./sec) = q × flow concentration factor

Manning's Roughness coefficient, n:
Assumed n = 0.03 for graded loam to cobbles (Ref: table 4.2, NUREG/CR-4620)

Depth of water, D:

Depth of water in ft., $D = \left[\frac{q_c \times n}{1.486\sqrt{S}}\right]^{\frac{3}{5}}$ (Ref: Eqn. 4.46, NUREG/CR-4620), where q_c is in cu. ft./sec

Permissible Velocity:
The cover permissible velocity is between 5 to 6 ft./sec (Ref: section 4.11.3, NUREG/CR-4620)

Flow Velocity, V:
Using continuity equation,
discharge = velocity × cross-sectional area

$\therefore q_c = V \times (D \times \text{unit width}) = V \times D \times 1$

$\therefore V(\text{in ft./sec}) = \frac{q_c}{D \times 1}$

For all the calculations provided in Table 1A and 2A for top of cover and side slopes respectively, $V_{developed} < V_{permissible}$

B: Calculation for Preliminary Size (D_{50}) of Rock Riprap used for Erosion Protection

B.1 Preliminary Size (D_{50}) of Riprap along Top of Cover

According to recommendations by U.S.N.R.C. [Ref: Appendix D, section 2.2 (step 5), "Final Staff Technical Position"], recent studies have indicated that Safety Factor method is more applicable for designing rock for slopes less than 10%. The slopes along top of the cover for all the cells 2, 3 and 4 do not exceed 10%. Hence the Safety Factor method has been adopted to calculate the median diameter D_{50} of the rock particles used for riprap.

According to the Safety Factor method for determination of stone size, if the Safety Factor (S.F.) is greater than unity, the riprap is considered to be safe from failure (Ref: Section 3.4.1,"Development of Riprap Design Criteria by Riprap Testing in Flumes", NUREG/CR-4651). For calculations to determine the riprap size for top of cover, a safety factor of 1.1 has been assumed and the D_{50} corresponding to this safety factor has been computed. Table 1B tabulates the results for the safety factor method.

The equations 3.5 through 3.9 of NUREG/CR-4651 (see appendix) for Safety Factor method are provided below :

$$SF = \frac{\cos\theta \tan\phi}{\eta' \tan\phi + \sin\theta \cos\beta}$$ ....eqn. A_1 (eqn. 3.5 of NUREG/CR-4651)

$$\eta' = \eta\left[\frac{1+\sin(\lambda+\beta)}{2}\right]$$ ....eqn. B_1 (eqn. 3.6 of NUREG/CR-4651)

$$\eta = \frac{21\tau_0}{(G_s-1)\gamma_w \times D_{50}}$$ ....eqn. C_1 (eqn. 3.7 of NUREG/CR-4651)

$$\tau_0 = \gamma_w DS$$ ....eqn. D_1 (eqn. 3.8 of NUREG/CR-4651)

$$\beta = \tan^{-1}\left[\frac{\cos\lambda}{\frac{2\sin\theta}{\eta\tan\phi} + \sin\lambda}\right]$$ ....eqn. E_1 (eqn 3.9 of NUREG/CR-4651)

where,

- λ = angle between a horizontal line and the velocity vector compoment measured in the plane of side slope (refer to fig. 3.1of NUREG/CR-4651)
- θ = side slope angle
- S = side slope = $\tan\theta$
- ϕ = angle of repose (friction angle) of rock

τ_0 = bed shear stress
D_{50} = representative stone size
G_s = Specific gravity or relative density of the rock
D = depth of flow
γ_w = specific weight of the liquid (in this case, water)
η & η' = stability numbers
β = angle between vector component of the weight, Ws, directed down the side slope and the direction of particle movement

For top of the cover, as slopes are very gentle, for all practical purposes, λ can be considered to be equal to zero (Ref: pg 22, NUREG/CR-4651)
Thus for $\lambda = 0$: $\cos\lambda = 1$, $\sin\lambda = 0$.
Hence, equation 3.9 of NUREG/CR-4651 can be reduced to

$$\beta = \tan^{-1}\left[\frac{\eta\tan\phi}{2\sin\theta}\right] \text{..........eqn } E_2 \text{ (eqn 3.10 of NUREG/CR-4651)}$$

Also, equation 3.6 of NUREG/CR-4651 can be reduced to

$$\eta' = \eta\left[\frac{1+\sin\beta}{2}\right] \text{..........eqn. } B_2$$

ϕ = 40° (see Table 3)
G_s = 2.48 (see Table 3)
γ_w = 62.4 lb./ft^3

The values for depth of water 'D' have been computed in Table 1A. Table 1B provides the preliminary D_{50} size for each of cells 2, 3 & 4 by varying the slope and the length of the drainage basin.

D_{50} calculated by CSU method

According to CSU method (Ref: NUREG/CR-4651, Phase-II),
$D_{50} = 5.23 \times (\text{slope})^{0.43} \times (\text{discharge})^{0.56}$
The results of D_{50} computed by CSU method have been included in table 1B (values of discharge have been computed in table 1A to compare with those obtained by Safety Factor method.

B.2 Preliminary Size (D_{50}) of Riprap along Side Slopes

According to recommendations by U.S.N.R.C. (Ref: Appendix D, section 2.2 (step 5), "Final Staff Technical Position"), recent studies have indicated that Stephenson method is more applicable for designing rock for slopes less than 10%. As the side slopes (5H:1V) have a value of S = 1/5 = 0.2 = 20%(>10%), the Stephenson method (Ref: "Development of Riprap Design Criteria by Riprap Testing in Flumes", NUREG/ CR-4651) will be most appropriate.

By **Stephenson method**, the median size for rock, D_{50} is given by the following equation (Ref: eqn. 3.15, NUREG/CR-4651):

$$D_{50} = \left[\frac{q_c (\tan\theta)^{\frac{7}{6}} \times n_p^{\frac{1}{6}}}{C\sqrt{g} \times [(1-n_p)(G_s-1)(\cos\theta)(\tan\phi - \tan\theta)]^{\frac{5}{3}}} \right]^{\frac{2}{3}}$$

where, q_c = Concentrated discharge in cu. ft./sec
θ = Slope angle = $\tan^{-1}$ (S) = $\tan^{-1}$ (0.2) = 11.31°
ϕ = Friction angle of the rock = 40° (see Table 3)
G_s = Relative Density of the rock = 2.48 (see Table 3)
g = Acceleration due to gravity = 32.2 ft./sec^2
n_p = Porosity of the rock = 0.30 (for sandstone) [Ref: (a) "Origin of Sedimentary Rocks" and (b) Table 3
C = Empirical factor [0.22 for gravel/pebble and 0.27 for crushed granite]
Also, K = Oliver's constant [1.2 for gravel and 1.8 for crushed rock]

The results for q_c from table 2A have been substituted into the above equation and the solution tabulated in table 2B. The value of D_{50} has been multiplied by the Oliver's constant K to insure stability.

D_{50} calculated by CSU method

According to CSU method (Ref: NUREG/CR-4651, Phase-II),

$D_{50} = 5.23 \times (\text{slope})^{0.43} \times (\text{discharge})^{0.56}$

The results of D_{50} computed by CSU method have been included in table 2B to compare with those obtained by Stephenson method.

C: Oversizing of Riprap based on durability and Overall Riprap Thickness

C.1 Modification of Size (D_{50}) of Riprap based on Durability

Tables 3 and 4 include the properties of the rock to be used as protective cover material. Based on these values and according to the scoring criteria set by U.S.N.R.C. (Ref: Appendix D, sections 6.2, 6.2.1,6.2.2 and table D-1 in "Final Staff Technical Position"), a rock rating analysis has been provided in Table 4. The results show a rock rating of 55.74%, which according to U.S.N.R.C. can be used for non critical areas like top slopes and side slopes.

Thus the oversizing required = 80-55.74 = 24.26%
[ref: (a) Appendix D, section 6.2.2B, "Final Staff Technical Position"; U.S.N.R.C. (oversizing required based on a 80-rating), (b) Appendix D, section 6.4 (example), "Final Staff Technical Position" and (c) Table 4.
However a oversizing factor of 25 % has been used. Thus the nominal diameter D_{50} obtained in tables 1B and 2B has been multiplied with 1.25 to obtain a modified rock size D_{50} (tables 1C and 2C).

C.2 Overall Riprap Thickness

According to the Safety Factor method, it is recommended that the riprap thickness be at least 1.5 times the D_{50} value whereas according to the Stephenson method the riprap thickness should be at least 2 times the D_{50} value. The results based on the above recommendations are shown in tables 1C and 2C respectively.

RESULTS:

Results of the calculations have been tabulated under tables 1A, 1B, 1C, 2A, 2B, 2C respectively.

REFERENCE:

a) "Final Staff Technical Position - Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites", 1990; U.S. Nuclear Regulatory Commission (U.S.N.R.C.)

b) Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments" (NUREG/CR-4620), 1986; U.S. Nuclear Regulatory Commission

c) "Development of Riprap Design Criteria by Riprap Testing in Flumes" (NUREG/CR-4651), 1987; U.S. Nuclear Regulatory Commission

d) National Oceanic and Atmospheric Administration (NOAA), 1977. Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages. Hydrometeorological Report (HMR) No. 49.

e) "Origin of Sedimentary Rocks", second edition; Harvey Blatt, Gerard Middleton and Raymond Murray

TABLES

TITAN ENVIRONMENTAL

Project #: 6111-001
Client: EFN, White Mesa
Location: Blanding, Utah

Date: June 1996
Prepared by: KG
Checked by:

Overland Flow Calculations for Top Portion of the Cover

Table 1A: Calculation for Runoff and Flow parameters

Cell No.	Maximum Length "L" of Drainage Basin (appx.)	Average Slope "S"	Drainage Area per ft. run A = L x 1 ft.		Manning's Roughness Coefficient n	1-hour precipitation amount	Design Storm	Time of Concentration,Tc: Calculated value (using Eqn.4.44, NUREG 4620)	Time of Concentration,Tc: Minimum value,based on table 2.1, NUREG 4620	Time of Concentration,Tc: Value used	%PMP = % of 1-hour precipitation (Table 2.1, NUREG 4620	Rainfall Depth	Precipitation Intensity "I"	Runoff Coefficient "C"	Flow Concentration Factor	Peak Discharge per unit ft. width q = CIA	Concentrated Discharge per unit ft. width q_c	Depth of water, "D" (eqn. 4.46, NUREG 4620)	Flow Velocity,V = Discharge / c.s. Area	Permissible Velocity
	ft.	ft./ft.	sq. ft.	Acres		inches		minutes	minutes	minutes		inches	inches/hr.			cu.ft./sec.	cu.ft./sec.	ft.	ft./sec.	ft./sec.
	1350	0.0080	1350	0.0310	0.03	7.76	PMP	12.88	2.5	12.88	68.90	5.35	24.92	0.8	3	0.62	1.85	0.593	3.13	
	1350	0.0072	1350	0.0310	0.03	7.76	PMP	13.41	2.5	13.41	70.18	5.45	24.37	0.8	3	0.60	1.81	0.604	3.00	
2	1350	0.0070	1350	0.0310	0.03	7.76	PMP	13.55	2.5	13.55	70.53	5.47	24.23	0.8	3	0.60	1.80	0.607	2.97	
	1350	0.0060	1350	0.0310	0.03	7.76	PMP	14.38	2.5	14.38	72.52	5.63	23.48	0.8	3	0.58	1.75	0.624	2.80	
	1350	0.0050	1350	0.0310	0.03	7.76	PMP	15.43	2.5	15.43	74.69	5.80	22.54	0.8	3	0.56	1.68	0.643	2.61	
	1350	0.0040	1350	0.0310	0.03	7.76	PMP	16.81	2.5	16.81	76.90	5.97	21.30	0.8	3	0.53	1.58	0.664	2.38	
	1350	0.0030	1350	0.0310	0.03	7.76	PMP	18.78	2.5	18.78	80.05	6.21	19.84	0.8	3	0.49	1.48	0.694	2.13	
	1350	0.0020	1350	0.0310	0.03	7.76	PMP	21.96	2.5	21.96	83.37	6.47	17.68	0.8	3	0.44	1.31	0.731	1.80	
	1350	0.0010	1350	0.0310	0.03	7.76	PMP	28.67	2.5	28.67	88.07	6.83	14.30	0.8	3	0.35	1.06	0.793	1.34	
	1100	0.0050	1100	0.0253	0.03	7.76	PMP	13.18	2.5	13.18	69.63	5.40	24.60	0.8	3	0.50	1.49	0.599	2.49	
	1100	0.0040	1100	0.0253	0.03	7.76	PMP	14.36	2.5	14.36	72.47	5.62	23.49	0.8	3	0.47	1.42	0.623	2.29	5 - 6
3	1100	0.0030	1100	0.0253	0.03	7.76	PMP	16.04	2.5	16.04	75.67	5.87	21.96	0.8	3	0.44	1.33	0.652	2.04	
	1100	0.0020	1100	0.0253	0.03	7.76	PMP	18.75	2.5	18.75	80.00	6.21	19.86	0.8	3	0.40	1.20	0.694	1.74	
	1100	0.0013	1100	0.0253	0.03	7.76	PMP	22.14	2.5	22.14	83.50	6.48	17.56	0.8	3	0.35	1.06	0.733	1.45	
	1100	0.0010	1100	0.0253	0.03	7.76	PMP	24.49	2.5	24.49	85.14	6.61	16.19	0.8	3	0.33	0.98	0.755	1.30	
	1250	0.0080	1250	0.0287	0.03	7.76	PMP	12.13	2.5	12.13	67.12	5.21	25.75	0.8	3	0.59	1.77	0.577	3.07	
	1250	0.0070	1250	0.0287	0.03	7.76	PMP	12.77	2.5	12.77	68.66	5.33	25.02	0.8	3	0.57	1.72	0.591	2.92	
4	1250	0.0060	1250	0.0287	0.03	7.76	PMP	13.56	2.5	13.56	70.53	5.47	24.23	0.8	3	0.56	1.67	0.607	2.75	
	1250	0.0057	1250	0.0287	0.03	7.76	PMP	13.83	2.5	13.83	71.18	5.52	23.97	0.8	3	0.55	1.65	0.612	2.70	
	1250	0.0050	1250	0.0287	0.03	7.76	PMP	14.54	2.5	14.54	72.90	5.66	23.34	0.8	3	0.54	1.61	0.627	2.57	
	1250	0.0040	1250	0.0287	0.03	7.76	PMP	15.85	2.5	15.85	75.35	5.85	22.14	0.8	3	0.51	1.52	0.649	2.35	
	1250	0.0030	1250	0.0287	0.03	7.76	PMP	17.70	2.5	17.70	78.32	6.08	20.60	0.8	3	0.47	1.42	0.678	2.09	
	1250	0.0020	1250	0.0287	0.03	7.76	PMP	20.69	2.5	20.69	82.48	6.40	18.56	0.8	3	0.43	1.28	0.719	1.78	
	1250	0.0010	1250	0.0287	0.03	7.76	PMP	27.02	2.5	27.02	86.92	6.74	14.98	0.8	3	0.34	1.03	0.778	1.33	

Rainfall Duration (min.)	% of 1-hr. precipitation
2.5	27.5
5	45
10	62
15	74
20	82
30	89
45	95
60	100

Table 2.1 of NUREG 4620

TITAN ENVIRONMENTAL

Project #: 6111-001
Client: EFN, White Mesa
Location: Blanding, Utah

Date: June 1996
Prepared by: KG
Checked by:

Riprap Design for Top portion of the Cover

Table 1B: Calculation for preliminary sizing of riprap, D50

Cell No.	Slope of Channel S (ft./ft.)	Slope of Channel θ (degrees)	Depth of flow, D (ft.)	Specific Weight of water γ_w (lb./cu. ft.)	Bed Shear Stress $\tau_0 = \gamma_w DS$ (lb./sq. ft.)	Rock Specific Gravity G_s	Angle of friction φ (degrees)	λ (degrees)	cos θ	sin θ	cos λ	sin λ	tan φ	D_{50} by Safety Factor method (inches)	D_{50} by Safety Factor method (ft.)	η	tan β	β (degrees)	cos β	η'	Safety Factor	D_{50} by CSU method (inches)
	0.0080	0.458	0.593	62.4	0.296	2.48	40	0	1.000	0.008	1.000	0.000	0.839	0.89	0.074	0.907	47.582	88.796	0.021	0.907	1.10	0.93
	0.0072	0.413	0.604	62.4	0.271	2.48	40	0	1.000	0.007	1.000	0.000	0.839	0.82	0.068	0.908	52.920	88.917	0.019	0.908	1.10	0.87
2	0.0070	0.401	0.607	62.4	0.266	2.48	40	0	1.000	0.007	1.000	0.000	0.839	0.80	0.066	0.910	54.520	88.949	0.018	0.910	1.10	0.86
	0.0060	0.344	0.624	62.4	0.233	2.48	40	0	1.000	0.006	1.000	0.000	0.839	0.70	0.058	0.910	63.634	89.100	0.016	0.910	1.10	0.79
	0.0050	0.286	0.643	62.4	0.201	2.48	40	0	1.000	0.005	1.000	0.000	0.839	0.60	0.050	0.912	76.519	89.251	0.013	0.912	1.10	0.72
	0.0040	0.229	0.664	62.4	0.166	2.48	40	0	1.000	0.004	1.000	0.000	0.839	0.50	0.041	0.912	95.661	89.401	0.010	0.912	1.10	0.63
	0.0030	0.172	0.694	62.4	0.130	2.48	40	0	1.000	0.003	1.000	0.000	0.839	0.39	0.033	0.909	127.126	89.549	0.008	0.909	1.10	0.53
	0.0020	0.115	0.731	62.4	0.091	2.48	40	0	1.000	0.002	1.000	0.000	0.839	0.28	0.023	0.906	189.975	89.698	0.005	0.906	1.10	0.42
	0.0010	0.057	0.793	62.4	0.049	2.48	40	0	1.000	0.001	1.000	0.000	0.839	0.15	0.012	0.912	382.676	89.850	0.003	0.912	1.10	0.28
	0.0050	0.286	0.599	62.4	0.187	2.48	40	0	1.000	0.005	1.000	0.000	0.839	0.56	0.047	0.911	76.415	89.250	0.013	0.911	1.10	0.67
	0.0040	0.229	0.623	62.4	0.156	2.48	40	0	1.000	0.004	1.000	0.000	0.839	0.47	0.039	0.913	95.721	89.401	0.010	0.913	1.10	0.59
3	0.0030	0.172	0.652	62.4	0.122	2.48	40	0	1.000	0.003	1.000	0.000	0.839	0.37	0.030	0.913	127.661	89.551	0.008	0.913	1.10	0.50
	0.0020	0.115	0.694	62.4	0.087	2.48	40	0	1.000	0.002	1.000	0.000	0.839	0.26	0.022	0.908	190.567	89.699	0.005	0.908	1.10	0.40
	0.0013	0.074	0.733	62.4	0.059	2.48	40	0	1.000	0.001	1.000	0.000	0.839	0.18	0.015	0.912	294.196	89.805	0.003	0.912	1.10	0.31
	0.0010	0.057	0.755	62.4	0.047	2.48	40	0	1.000	0.001	1.000	0.000	0.839	0.14	0.012	0.906	379.944	89.849	0.003	0.906	1.10	0.27
	0.0080	0.458	0.577	62.4	0.288	2.48	40	0	1.000	0.008	1.000	0.000	0.839	0.87	0.072	0.909	47.686	88.799	0.021	0.909	1.10	0.90
	0.0070	0.401	0.591	62.4	0.258	2.48	40	0	1.000	0.007	1.000	0.000	0.839	0.78	0.065	0.908	54.460	88.948	0.018	0.908	1.10	0.84
	0.0060	0.344	0.607	62.4	0.227	2.48	40	0	1.000	0.006	1.000	0.000	0.839	0.68	0.057	0.912	63.742	89.101	0.016	0.912	1.10	0.77
4	0.0057	0.327	0.612	62.4	0.218	2.48	40	0	1.000	0.006	1.000	0.000	0.839	0.66	0.055	0.907	66.776	89.142	0.015	0.907	1.10	0.75
	0.0050	0.286	0.627	62.4	0.196	2.48	40	0	1.000	0.005	1.000	0.000	0.839	0.59	0.049	0.912	76.531	89.251	0.013	0.912	1.10	0.70
	0.0040	0.229	0.649	62.4	0.162	2.48	40	0	1.000	0.004	1.000	0.000	0.839	0.49	0.040	0.912	95.624	89.401	0.010	0.912	1.10	0.62
	0.0030	0.172	0.678	62.4	0.127	2.48	40	0	1.000	0.003	1.000	0.000	0.839	0.38	0.032	0.911	127.413	89.550	0.008	0.911	1.10	0.52
	0.0020	0.115	0.719	62.4	0.090	2.48	40	0	1.000	0.002	1.000	0.000	0.839	0.27	0.023	0.907	190.227	89.699	0.005	0.907	1.10	0.41
	0.0010	0.057	0.778	62.4	0.048	2.48	40	0	1.000	0.001	1.000	0.000	0.839	0.15	0.012	0.908	380.792	89.850	0.003	0.908	1.10	0.27

Table 1C: Diameter of Riprap modified based on durability, and Overall Riprap Thickness

Cell No.	Slope of channel S (ft./ft.)	D_{50} based on Safety Factor Method (inches)	Oversizing Factor based on Rock Quality (from previous report)	Modified D_{50} after oversizing (inches)	Thicknes of Riprap layer =1.5xD_{50} (inches)	Overall Riprap Thickness suggested (inches)
	0.0080	0.89	1.25	1.11	1.67	
	0.0072	0.82	1.25	1.02	1.53	
	0.0070	0.80	1.25	0.99	1.49	
2	0.0060	0.70	1.25	0.88	1.31	
	0.0050	0.60	1.25	0.75	1.13	
	0.0040	0.50	1.25	0.62	0.93	
	0.0030	0.39	1.25	0.49	0.73	
	0.0020	0.28	1.25	0.34	0.52	
	0.0010	0.15	1.25	0.19	0.28	
	0.0050	0.56	1.25	0.70	1.05	
	0.0040	0.47	1.25	0.58	0.87	
3	0.0030	0.37	1.25	0.46	0.68	3
	0.0020	0.26	1.25	0.33	0.49	
	0.0013	0.18	1.25	0.22	0.33	
	0.0010	0.14	1.25	0.18	0.27	
	0.0080	0.87	1.25	1.08	1.62	
	0.0070	0.78	1.25	0.97	1.45	
	0.0060	0.68	1.25	0.85	1.28	
	0.0057	0.66	1.25	0.82	1.23	
4	0.0050	0.59	1.25	0.73	1.10	
	0.0040	0.49	1.25	0.61	0.91	
	0.0030	0.38	1.25	0.48	0.71	
	0.0020	0.27	1.25	0.34	0.51	
	0.0010	0.15	1.25	0.18	0.27	

TITAN ENVIRONMENTAL

Project #: 6111-001
Client: EFN, White Mesa
Location: Blanding, Utah

Date: June 1996
Prepared by: KG
Checked by:

Overland Flow Calculations for Side Slopes of the Cover

Table 2A: Calculation for Runoff and Flow parameters

Maximum Length, "L" of Drainage Basin (appx)	Average Slope "S"	Drainage Area per ft. run A = L x 1 ft.		Manning's Roughness Coefficient n	1-hour precipitation amount	Design storm	Time of Concentration, Tc			% PMP % of 1-hour precipitation (Table 2.1, NUREG 4620	Precipitation Amount	Precipitation intensity "i"	Runoff Coefficient "C"	Flow Concentra-tion Factor	Peak Discharge per unit ft. width q = CiA	Concentrated Discharge per unit ft. width q_c	Depth of water, "D" (eqn. 4.46, NUREG 4620)	Flow Velocity, V = Discharge / c.s. Area	Permissible Velocity (sec. 4.11.3 of (NUREG 4620)
							Calculated value (using Eqn.4.44, NUREG 4620)	Minimum value based on table 2.1, NUREG 4620	Value used										
ft.	ft./ft.	sq. ft.	Acres		inches		minutes	minutes	minutes		inches	inches/hr.			cu.ft./sec.	cu.ft./sec.	ft.	ft./sec.	ft./sec.
275	0.2000	275	0.0063	0.03	7.76	PMP	1.10	2.5	2.5	27.5	2.13	51.22	0.8	2	0.26	0.52	0.105	4.93	5 - 6

Rainfall Duration (min.)	% of 1-hr. precipitation
2.5	27.5
5	45
10	62
15	74
20	82
30	89
45	95
60	100

TITAN ENVIRONMENTAL

Project #: 6111-001
Client: EFN, White Mesa
Location: Blanding, Utah

Date: June 1996
Prepared by: KG
Checked by:

Riprap Design for Side Slopes of the Cover

Table 2B: Calculation for preliminary sizing of riprap, D_{50}

Slope of Channel		Angle of friction for rock	Concentrated discharge per unit ft. width, q_c	Relative density of Rock	Porosity	Type of Riprap	Stephenson Constant	tan θ	cos θ	tan φ	D_{50} by Stephenson Method (Eqn. 4.28 of NUREG 4620)		Oliver's Constant	Modified D_{50}	D_{50} based on CSU method
S	θ	φ		G_s	n_p		C						K		
ft./ft.	degrees	degrees	cu. ft./sec								ft.	inches		inches	ft.
0.200	11.310	40	0.52	2.48	0.3	gravel/pebbles	0.22	0.200	0.981	0.839	0.22	2.70	1.2	3.235	1.81
0.200	11.310	40	0.52	2.48	0.3	crushed granite	0.27	0.200	0.981	0.839	0.20	2.35	1.8	4.234	1.81

Table 2C: Diameter of Riprap modified based on durability, and Overall Riprap Thickness

Slope of channel S	D_{50} based on Stephenson Method	Oversizing Factor based on Rock Quality (from previous report)	Modified D_{50} after oversizing	Thickness of Riprap layer $= 2 \times D_{50}$	Overall Riprap Thickness suggested	Type of Riprap
ft./ft.	inches		inches	inches	inches	
0.200	3.235	1.25	4.04	8.09	12	gravel/pebbles
0.200	4.234	1.25	5.29	10.58	12	crushed granite

TABLE 3

WHITE MESA CHANNEL A ROCK APRON

RIPRAP SIZING – STEPHENSON'S METHOD

	ENTER		WITH 24% OVERSIZE
UNIT FLOW RATE "q"	4.27	CFS/FT	
ROCKFILL POROSITY – n	0.3		
SLOPE ANGLE	11.3	DEGREES	
FRICTION ANGLE	40	DEGREES	
SPECIFIC GRAVITY OF ROCK	2.48		
D–100 (BASED ON 1.25xD50)	12.00	INCHES	14.88"
D–50	9.60	INCHES	12.6"

WHITE MESA CHANNEL B ROCK APRON

RIPRAP SIZING – STEPHENSON'S METHOD

	ENTER		
UNIT FLOW RATE "q"	3.26	CFS/FT	
ROCKFILL POROSITY – n	0.3		
SLOPE ANGLE	11.3	DEGREES	
FRICTION ANGLE	40	DEGREES	
SPECIFIC GRAVITY OF ROCK	2.48		
D–100 (BASED ON 1.5xD50)	12.03	INCHES	14.9"
D–50	8.02	INCHES	9.94"

TABLE 4

NRC SCORING CRITERIA FOR DETERMINING ROCK QUALITY
WHITE MESA ROCK PROTECTION

ROCK TYPE: 2

Limestone = 1
Sandstone = 2
Igneous = 3

LABORATORY TEST	TEST RESULT	SCORE	WEIGHT	SCORE * WEIGHT	MAX. SCORE
Specific Gravity	2.48	4.60	6	27.60	60.00
Absorption, %	1.75	3.50	5	17.50	50.00
Sodium Sulfate, %	0.60	10.00	3	30.00	30.00
L/A Abrasion (100 revs), %	8.40	5.94	8	47.53	80.00
Schmidt Hammer	0.00	0.00	13	0.00	0.00
Tensile Strength, psi	0.00	0.00	4	0.00	0.00

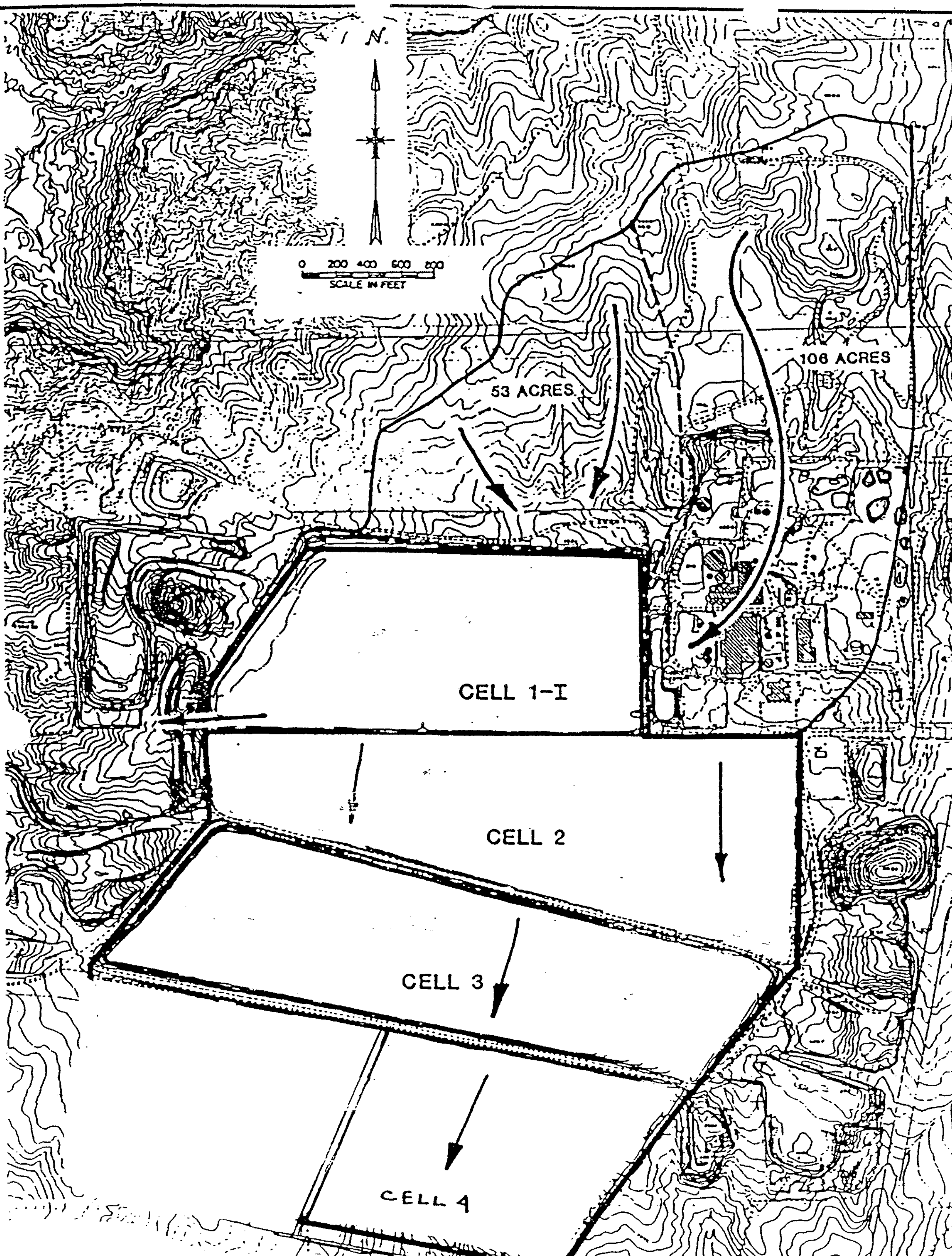
ROCK RATING, %: 55.74

RATING ANALYSIS:

Critical Areas– REJECTED
Oversizing, % =

Non–Critical Areas– OVERSIZING REQUIRED
Oversizing, % = 24

FIGURE



WHITE MESA PROJECT

SITE DRAINAGE

FIGURE: 1

APPENDIX

FINAL

STAFF TECHNICAL POSITION

DESIGN OF EROSION PROTECTION COVERS FOR

STABILIZATION OF URANIUM MILL TAILINGS SITES

U. S. Nuclear Regulatory Commission

August 1990

FINAL
STAFF TECHNICAL POSITION
DESIGN OF EROSION PROTECTION COVERS FOR
STABILIZATION OF URANIUM MILL TAILINGS SITES

1. INTRODUCTION

Criteria and standards for environmental protection may be found in the Uranium Mill Tailings Radiation Control Act (UMTRCA) of 1978 (PL 95-604) (see Ref. 1) and 10 CFR Section 20.106, "Radioactivity in Effluents to Unrestricted Areas." In 1983, the U. S. Environmental Protection Agency (EPA) established standards (40 CFR Part 192) for the final stabilization of uranium mill tailings for inactive (Title I) and active (Title II) sites. In 1980, the United States Nuclear Regulatory Commission (NRC) promulgated regulations (10 CFR Part 40, Appendix A) for active sites and later revised Appendix A to conform to the standards in 40 CFR Part 192. These standards and regulations establish the criteria to be met in providing long-term stabilization.

These regulations also prescribe criteria for control of tailings. For the purpose of this staff technical position (STP), control of tailings is defined as providing an adequate cover to protect against exposure or erosion of the tailings. To help licensees and applicants meet Federal guidelines, this STP describes design practices the NRC staff has found acceptable for providing such protection for 200 to 1000 years and focuses principally on the design of tailings covers to provide that protection.

Presently, very little information exists on designing covers to remain effective for 1000 years. Numerous examples can be cited where covers for protection of tailings embankments and other applications have experienced significant erosion over relatively short periods (less than 50 years). Experience with reclamation of coal-mining projects, ror example, indicates that it is usually necessary to provide relatively flat slopes to maintain overall site stability (Wells and Jercinovic, 1983, see Ref. 2).

Because of the basic lack of design experience and technical information in this area, this position attempts to adapt standard hydraulic design methods and empirical data to the design of erosion protection covers. The design methods discussed here are based either on: (1) the use of documented hydraulic procedures that are generally applicable in any area of hydraulic design; or (2) the use of procedures developed by technical assistance contractors specifically for long-term stability applications.

It should be emphasized that a standard industry practice for stabilizing tailings for 1000 years does not currently exist. However, standard practice does exist for providing stable channel sections. This practice is widely used to design drainage channels that do not erode when subjected to design flood flows. Since an embankment slope can be treated as a wide channel, the staff concludes that the hydraulic design principles and practice associated with

2.1.2 Long-Term Stability

As required by 40 CFR 192.02 and 10 CFR Part 40, Appendix A, Criterion 6, stabilization designs must provide reasonable assurance of control of radiological hazards for a 1000-year period, to the extent practicable, but in any case, for a minimum 200-year period. The NRC staff has concluded that the risks from tailings could be accommodated by a design standard that requires that there be reasonable assurance that the tailings remain stable for a period of 1000 (or at least 200) years, preferably with reliance placed on passive controls (such as earth and rock covers), rather than routine maintenance.

2.1.3 Design for Minimal Maintenance

Criteria for tailings stabilization, with minimal reliance placed on active maintenance, are established in 40 CFR Part 192 and 10 CFR Part 40, Appendix A, Criteria 1 and 12. Criterion 1 of 10 CFR Part 40, Appendix A specifically states that: "Tailings should be disposed of in a manner [such] that no active maintenance is required to preserve conditions of the site." Criterion 12 states that: "The final disposition of tailings or wastes at milling sites should be such that ongoing active maintenance is not necessary to preserve isolation."

It is evident that remedial action designs are intended to last for a long time, without the need for active maintenance. Therefore, in accordance with regulatory requirements, the NRC staff has concluded that the goal of any design for long-term stabilization to meet applicable design criteria should be to provide overall site stability for very long time periods, with no reliance placed on active maintenance.

For the purposes of this STP, active maintenance is defined as any maintenance that is <u>needed</u> to assure that the design will meet specified longevity requirements. Such maintenance includes even minor maintenance, such as the addition of soil to small rills and gullies. The question that must be answered is whether longevity is dependent on the maintenance. If it is necessary to repair gullies, for example, to prevent their growth and ultimate erosion into tailings, then that maintenance is considered to be active maintenance.

2.1.4 Radon Release Limits

Titles 40 CFR 192.02 and 10 CFR Part 40, Appendix A require that earthen covers be placed over tailings at the end of milling operations to limit releases of radon-222 to not more than an average of 20 picocuries per square meter per second (pCi/m^2s), when averaged over the entire surface of the disposal site and over at least a one-year period, for the control period of 200 to 1000 years. Before placement of the cover, radon release rates are calculated in designing the protective covers and barriers for uranium mill tailings. Additionally, recent regulations promulgated under the Clean Air Act design follows the procedure for a soil cover, because the layer is predominantly soil, rather than rock.

2.2 Design Procedures

A step-by-step procedure for designing riprap for the top and side slopes of a reclaimed pile is presented below:

Step 1. Determine the drainage areas for both the top slope and the side slope. These drainage areas are normally computed on a unit-width basis.

Step 2. Determine time of concentration (tc).

The tc is usually a difficult parameter to estimate in the design of a rock layer. Based on a review of the various methods for calculating tc, the NRC staff concludes that a method such as the Kirpich method, as discussed by Nelson, et al. (1986, see Ref. D2), should be used. The tc may be calculated using the formula:

$$tc = (11.9L^3/H)^{.385}$$, where L = drainage length (in miles)

H = elevation difference (in feet)

Step 3. Determine Probable Maximum Flood (PMF) and Probable Maximum Precipitation (PMP).

Techniques for PMP determinations have been developed for the entire United States, primarily by the National Oceanographic and Atmospheric Administration, in the form of hydrometeorological reports for specific regions. These techniques are commonly accepted and provide straightforward procedures for assessing rainfall potential, with minimal variability. Acceptable methods for determining the total magnitude of the PMP and various PMP intensities for specific times of concentration are given by Nelson, et al. (1986, see Ref. D2, Section 2.1).

Step 4. Calculate peak flow rate.

The Rational Formula, as discussed by Nelson et al. (1986, see Ref. D2), may be used to calculate peak flow rates for these small drainage areas. Other methods that are more precise are also acceptable; the Rational Formula was chosen for its simplicity and ease of computation.

Step 5. Determine rock size.

Using the peak flow rate calculated in Step 4, the required D_{50} may be determined. Recent studies performed for the NRC staff (Abt, et al., 1988, see Ref. D3) have indicated that the Safety Factors Method is more applicable for designing rock for slopes less than 10 percent and that the Stephenson Method is more applicable for slopes greater than 10 percent. Other methods may also be used, if properly justified.

2.3 Recommendations

Since it is unlikely that clogging of the riprap voids will not occur over a long period of time, it is suggested that no credit be taken for flow through the riprap voids. Even if the voids become clogged, it is unlikely that stability will be affected, as indicated by tests performed for the NRC staff by Abt, et al. (1987, see Ref. D4).

If rounded rather than angular rock is used, some increase in the average rock size may be necessary, since the rock will not be as stable. Computational models, such as the Safety Factors Method, provide stability coefficients for different angles of repose of the material. The need for oversizing of rounded rock is further discussed by Abt, et al. (1987, see Ref. D4).

2.4 Example of Procedure Application

Determine the riprap requirements for a tailings pile top slope with a length of 1000 feet and a slope of 0.02 and for the side slope with an additional length of 250 feet and a slope of 0.2 (20 percent).

Step 1. The drainage areas for the top slope (A1) and the side slope (A2) on a unit-width basis are computed as follows:

$$A1 = (1000)\ (1)\ /\ 43560 = 0.023 \text{ acres}$$

$$A2 = (1000 + 250)\ (1)\ /\ 43560 = 0.029 \text{ acres.}$$

Step 2. The tcs are individually computed for the top and side slopes, using the Kirpich Method, as discussed by Nelson, et al. (1986, see Ref. D2).

$$tc = [(11.9)(L)^3/H]^{.385}$$

For L = 1000 feet and H = 20 feet,

tc = 0.12 hours = 7.2 minutes for the top slope

For L = 250 feet and H = 50 feet,

tc = 1.0 minute for the side slope.

Therefore, the total tc for the side slope is equal to 7.2 + 1.0, or 8.2 minutes.

Step 3. The rainfall intensity is determined using procedures discussed by Nelson, et al. (1986, see Ref. D2), based on a 7.2-minute PMP of 4.2 inches for the top slope and an 8.2-minute PMP of approximately 4.5 inches for the side slope. These incremental PMPs are based on a one-hour PMP of 8.0 inches for northwestern New Mexico and were derived using procedures discussed by Nelson, et al. (1986, see Ref. D2).

Rainfall intensities, for use in the Rational Formula, are computed as follows:

i_1 = (60)(4.2)/7.2 = 35 inches/hr for the top slope

i_2 = (60)(4.5)/8.2 = 33 inches/hr for the side slope.

Step 4. Assuming a runoff coefficient (C) of 0.8, the peak flow rates are calculated using the Rational Formula, as follows:

Q1 = (0.8) (35) (0.023) = 0.64 cfs/ft, for the top slope, and

Q2 = (0.8) (33) (0.029) = 0.77 cfs/ft, for the side slope.

Step 5. Using the Safety Factors Method, the required rock size for the pile top slope is calculated to be:

D_{50} = 0.6 inches.

Using the Stephenson Method, the required rock size for the side slopes is calculated to be:

D_{50} = 3.1 inches.

2.5 Limitations

The use of the aforementioned procedures is widely applicable. The Stephenson Method is an empirical approach and is not applicable to gentle slopes. The Safety Factors Method is conservative for steep slopes. Other methods may also be used, if properly justified.

3. RIPRAP DESIGN FOR DIVERSION CHANNELS

3.1 Technical Basis

The Safety Factors Method or other shear stress methods are generally accepted as reliable methods for determining riprap requirements for channels. These methods are based on a comparison of the stresses exerted by the flood flows with the allowable stress permitted by the rock. Documented methods are readily available for determining flow depths and Manning "n" values.

3.2 Design Procedures

3.2.1 Normal Channel Designs

In designing the riprap for a diversion channel where there are no particularly difficult erosion considerations, the design of the erosion protection is relatively straightforward.

1. The Safety Factors Method or other shear stress methods may be used to determine the riprap requirements.

2. The peak shear stress should be used for design purposes and can be determined ty substituting the value of the depth of flow (y) in the shear

6. OVERSIZING OF MARGINAL-QUALITY EROSION PROTECTION

6.1 Technical Basis

The ability of some rock to survive without significant degradation for long time periods is well-documented by archaeological and historic evidence (Lindsey, et al., 1982, see Ref. D13). However, very little information is available to quantitatively assess the quality of rock needed to survive for long periods, based on its physical properties.

In assessing the long-term durability of erosion protection materials, the NRC staff has relied principally on the results of durability tests at several sites and on information, analyses, and methodology presented in NUREG/CR-4620 (Nelson, et al., see Ref. D2). This document provides a quantitative method for determining the oversizing requirements for a particular rock type to be placed at specific locations on or near a remediated uranium mill tailings pile.

Staff review of actual field data from several tailings sites has indicated that the methodology may not be sufficiently flexible to allow the use of "borderline" quality rock, where a particular type of rock fails to meet minimum qualifications for placement in a specific zone, but fails to qualify by only a small amount. This may be very important, since the selection of a particular rock type and rock size depends on its quality and where it will be placed on the embankment.

Based on NRC staff review of the actual field data, the methodology previously derived has been modified to incorporate additional flexibility. These revisions include modifications to the quality ratings required for use in a particular placement zone, re-classification of the placement zones, reassessment of weighting factors based on the rock type, and more detailed procedures for computing rock quality and the amount of oversizing required.

Based on an examination of the actual field performance of various types and quality of rock (Esmiol, 1967, see Ref. D14), the NRC staff considers it important to determine rock properties with a petrographic examination. The case history data indicated that the singlemost important factor in rock deterioration was the presence of smectites and expanding lattice clay minerals. Therefore, if a petrographic examination indicates the presence of such minerals, the rock will not be suitable for long-term applications.

6.2 Design Procedures

Design procedures and criteria have been developed by the NRC staff for use in selecting and evaluating rock for use as riprap to survive long time periods. The methods are considered to be flexible enough to accommodate a wide range of rock types and a wide range of rock quality for use in various long-term stability applications.

The first step in the design process is to determine the quality of the rock, based on its physical properties. The second step is to determine the amount of oversizing needed, if the rock is not of good quality. Various combinations of good-quality rock and oversized marginal-quality rock may also be considered in the design, if necessary.

6.2.1 Procedures for Assessing Rock Quality

The suitability of rock to be used as a protective cover should be assessed by laboratory tests to determine the physical characteristics of the rocks. Several durability tests should be performed to classify the rock as being of poor, fair (intermediate), or good quality. For each rock source under consideration, the quality ratings should be based on the results of about three to four different durability test methods for initial screening and about six test methods for final sizing of the rock(s) selected for inclusion in the design. Procedures for determining the rock quality and determining a rock quality "score" are developed in Table D1.

6.2.2 Oversizing Criteria

Oversizing criteria vary, depending on the location where the rock will be placed. Areas that are frequently saturated are generally more vulnerable to weathering than occasionally-saturated areas where freeze/thaw and wet/dry cycles occur less frequently. The amount of oversizing to be applied will also depend on where the rock will be placed and its importance to the overall performance of the reclamation design. For the purposes of rock oversizing, the following criteria have been developed:

A. Critical Areas. These areas include, as a minimum, frequently-saturated areas, all channels, poorly-drained toes and aprons, control structures, and energy dissipation areas.

Rating

80-100 - No Oversizing Needed

65-80 - Oversize using factor of (80-Rating), expressed as the percent increase in rock diameter. For example, a rock with a rating of 70 will require oversizing of 10 percent. (See example of procedure application, given in Section 6.4, p. D-28)

Less than 65 - Reject

B. Non-Critical Areas. These areas include occasionally-saturated areas, top slopes, side slopes, and well-drained toes and aprons.

Rating

80-100	-	No Oversizing Needed
50-80	-	Oversize using factor of (80-Rating), expressed as the percent increase in rock diameter

Less than 50 - Reject

TABLE D1

Scoring Criteria for Determining Rock Quality

Laboratory Test	Weighting Factor			Score										
	Limestone	Sandstone	Igneous	10	9	8	7	6	5	4	3	2	1	0
					Good			Fair			Poor			
Sp. Gravity	12	6	9	2.75	2.70	2.65	2.60	2.55	2.50	2.45	2.40	2.35	2.40	2.25
Absorption, %	13	5	2	.1	.3	.5	.67	.83	1.0	1.5	2.0	2.5	3.0	3..
Sodium Sulfate, %	4	3	11	1.0	3.0	5.0	6.7	8.3	10.0	12.5	15.0	20.0	25.0	30.0
L/A Abrasion (100 revs), %	1	8	1	1.0	3.0	5.0	6.7	8.3	10.0	12.5	15.0	20.0	25.0	30.0
Schmidt Hammer	11	13	?	70.0	65.0	60.0	54.0	47.0	40.0	32.0	24.0	16.0	8.0	0.0
Tensile Strength, psi	6	4	10	1400	1200	1000	833	666	500	400	300	200	100	0

1. Scores were derived from Tables 6.2, 6.5, and 6.7 of NUREG/CR-2642 - "Long-Term Survivability of Riprap for Armoring Uranium Mill Tailings and Covers: A Literature Review," 1982 (see Ref. D13).

2. Weighting Factors are derived from Table 7 of "Petrographic Investigations of Rock Durability and Comparisons of Various Test Procedures," by G. W. DuPuy, Engineering Geology, July, 1965 (see Ref. D15). Weighting factors are based on inverse of ranking of test methods for each rock type. Other tests may be used; weighting factors for these tests may be derived using Table 7, by counting upward from the bottom of the table.

3. Test methods should be standardized, if a standard test is available and should be those used in NUREG/CR-2642 (see Ref. D13), so that proper correlations can be made. This is particularly important for the tensile strength test, where several methods may be used; the method discussed by Nilsson (1962, see Ref. D16) for tensile strength was used in the scoring procedure.

6.3 Recommendations

Based on the performance histories of various rock types and the overall intent of achieving long-term stability, the following recommendations should be considered in assessing rock quality and determining riprap requirements for a particular design.

1. The rock that is to be used should first be qualitatively rated at least "fair" in a petrographic examination conducted by a geologist or engineer experienced in petrographic analysis. See NUREG/CR-4620, Table 6.4 (see Ref. D2), for general guidance on qualitative petrographic ratings. In addition, if a rock contains smectites or expanding lattice clay minerals, it will not be acceptable.

2. An occasionally-saturated area is defined as an area with underlying filter blankets and slopes that provide good drainage and are steep enough to preclude ponding, considering differential settlement, and are located well above normal groundwater levels; otherwise, the area is classified as frequently-saturated. Natural channels and relatively flat man-made diversion channels should be classified as frequently-saturated. Generally, any toe or apron located below grade should be classified as frequently-saturated; such toes and aprons are considered to be poorly-drained in most cases.

3. Using the scoring criteria given in Table D1, the results of a durability test determines the score; this score is then multiplied by the weighting factor for the particular rock type. The final rating should be calculated as the percentage of the maximum possible score for all durability tests that were performed. See example of procedure application for additional guidance on determining final rating.

4. For final selection and oversizing, the rating may be based on the durability tests indicated in the scoring criteria. Other tests may also

be substituted or added, as appropriate, depending on rock type and site-specific factors. The durability tests given in Table D1 are not intended to be all-inclusive. They represent some of the more commonly-used tests or tests where data may be published or readily-available. Designers may wish to use other tests than those presented; such an approach is acceptable. Scoring criteria may be developed for other tests, using procedures and references recommended in Table D1. Further, if a rock type barely fails to meet minimum criteria for placement in a particular area, with proper justification and documentation, it may be feasible to throw out the results of a test that may not be particularly applicable and substitute one or more tests with higher weighting factors, depending on the rock type or site location. In such cases, consideration should be given to performing several additional tests. The additional tests should be those that are among the most applicable tests for a specific rock type, as indicated by the highest weighting factors given in the scoring criteria for that rock type.

5. The percentage increase of oversizing should be applied to the diameter of the rock.

6. The oversizing calculations represent minimum increases. Rock sizes as large as practicable should be provided. (It is assumed, for example, that a 12-inch layer of 4-inch rock costs the same as a 12-inch layer of 6-inch rock.) The thickness of the rock layer should be based on the constructability of the layer, but should be at least 1.5 x D_{50}. Thicknesses of less than 6 inches may be difficult to construct, unless the rock size is relatively small.

6.4 Example of Procedure Application

It is proposed that a sandstone rock source will be used. The rock has been rated "fair" in a petrographic examination. Representative test results are given. Compute the amount of oversizing necessary.

Using the scoring criteria in Table D1, the following ratings are computed:

Lab Test	Result	Score	Weight	Score x Weight	Max. Score
Sp. Gr.	2.61	7	6	42	60
Absorp., %	1.22	4	5	20	50
Sod. Sulf., %	6.90	6	3	18	30
L.A. Abr., %	8.70	5	8	40	80
Sch. Ham.	51	6	13	78	130
Tens. Str., psi	670	6	4	24	40
Totals				222	390

The final rating is computed to be 222/390 or 57 percent. As discussed in Section 6.2, the rock is not suitable for use in frequently-saturated areas, but is suitable for use in occasionally-saturated areas, if oversized. The oversizing needed is equal to (80 - 57), or a 23 percent increase in rock diameter.

6.5 Limitations

The procedure previously presented is intended to provide an approximate quantitative method of assessing rock quality and rock durability. Although the procedure should provide rock of reasonable quality, additional data and studies are needed to establish performance histories of rock types that have a score of a specific magnitude. It should be emphasized that the procedure is only a more quantitative estimate of rock quality, based on USBR classification standards.

It should also be recognized that durability tests are not generally intended to determine if rock will actually deteriorate enough to adversely affect the stability of a reclaimed tailings pile for a design life of 200 to 1000 years. These tests are primarily intended to determine acceptability of rock for various construction purposes for design lifetimes much shorter than 1000 years. Therefore, although higher scores give a higher degree of confidence that significant deterioration will not occur, there is not complete assurance that deterioration will not occur. Further, typical construction projects rely on planned maintenance to correct deficiencies. It follows, then, that there is also less assurance that the oversizing methodology will actually result in rock that will only deteriorate a given amount in a specified time period. The amount of oversizing resulting from these calculations is based on the engineering judgment of the NRC staff, with the assistance of contractors. However, in keeping with the Management Position (USNRC, 1989, see Ref. D17), the staff considers that this methodology will provide reasonable assurance of the effectiveness of the rock over the design lifetime of the project.

7. REFERENCES

D1. Nelson et al., "Design Considerations for Long-Term Stabilization of Uranium Mill Tailings Impoundments," NUREG/CR-3397 (ORNL-5979), U.S. Nuclear Regulatory Commission, Washington, D.C., 1983.

D2. Nelson, et al., "Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailing Impoundments," NUREG/CR-4620, 1986.

D3. Abt, S. R., et al., "Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase II," NUREG/CR-4651, Vol. 2, 1988.

D4. Abt, S. R., et al., "Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase I," NUREG/CR-4651, Vol. 1, 1987.

D5. U.S. Army Corps of Engineers (USCOE), "Hydraulic Design of Flood Control Channels," EM 1110-2-1601, Office of the Chief of Engineers, Washington, D.C., 1970.

D6. Chow, V. T., Open-Channel Hydraulics, McGraw-Hill Book Company, Inc., New York, N.Y., 1959.

D7. U.S. Army Corps of Engineers (USCOE), Hydrologic Engineering Center, "Water Surface Profiles, HEC-2," continuously updated and revised.

D8. U.S. Department of Transportation (USDOT), "Hydraulic Design of Energy Dissipators for Culverts and Channels," Hydraulic Engineering Circular No. 14, 1983.

D9. U.S. Bureau of Reclamation (USBR), Design of Small Dams, 1977.

NUREG/CR-4620
ORNL/TM-10067

Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments

Manuscript Completed: May 1986
Date Published: June 1986

Prepared by
J. D. Nelson, S. R. Abt, R. L. Volpe, D. van Zyl, Colorado State University
N. E. Hinkle, W. P. Staub, Oak Ridge National Laboratory

Colorado State University
Fort Collins, CO 80523

Under Contract to:
Oak Ridge National Laboratory
Oak Ridge, TN 37831

Prepared for
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN B0279

The rainfall depth for a specific site is estimated by determining the rainfall duration and/or appropriate time of concentration. The resulting rainfall depth in inches, is

$$\text{PMP rainfall depth} = (\%\ \text{PMP}) \times (\text{PMP}) \tag{2.1}$$

where the percent PMP is obtained from Table 2.1 and the PMP is obtained from the appropriate PMP design storm presented in Section 2.1.1.

The rainfall intensity, i, in inches per hour can be computed as

$$i = \text{rainfall depth (inches)} \times \frac{60}{\text{rainfall duration (minutes)}} \tag{2.2}$$

The rainfall intensity determined from Equation 2.2 is generally a conservative value and represents the peak rainfall intensity of the design storm.

To compute the rainfall intensity for any rainfall duration, it is recommended that a rainfall intensity versus rainfall duration curve be plotted on semilogarithmic paper. Because of the extremely conservative rainfall intensity values obtained for short durations, it is recommended that the minimum rainfall duration be 2.5 minutes. Rainfall depths should be extracted from the appropriate Hydrometeorological Report.

2.2 PMP COMPARISON STORMS

A comparison of estimates of the PMP with greatest observed rainfall and estimates of the 100-year events for areas both east and west of the 105° meridian was prepared (NWS, 1980). Information from 6500 precipitation reporting stations in the eastern U.S. and about 2100 stations in the west was used. Including storm durations of 6 to 72 hours, the study indicated that 177 separate storm events have been recorded in which the rainfall was greater than or equal to 50 percent of the PMP for stations east of the 105° meridian. Only 66 separate storm events were recorded west of the 105° meridian where rainfalls were greater than or equal to 50 percent of the PMP.

The National Weather Service also reported the number of storm events which met or exceeded the 100-year rainfall values and compared them with the regional PMP values (NWS, 1980). Table 2.2 summarizes these rainfall events for 6 and 24-hour storms occurring over a 10 square mile area. It is interesting to note that a storm has not been officially recorded west of the Continental Divide that exceeds 90% of the PMP value. However, it is evident that a number of storms approach the PMP values, thereby substantiating that the prescribed PMP values are not extremely conservative.

4.1.5.6 Gully Width

The width of the gully across the top of the gully at the point of maximum depth can be estimated from Figure 4.5. Having computed the maximum depth, D_{max}, and knowing the uniformity coefficient, C_u, the top width is estimated to be approximately 5.6 feet. However, the gully width will widen over time to where the gully side wall stands at an angle less than the angle of repose of the cover material.

4.2 EMBANKMENT AND SLOPE STABILIZATION USING RIPRAP

Rock riprap is one of the most economical materials that is commonly used to provide for cover and slope protection. Factors to consider when designing rock riprap are: (1) rock durability, density, size, shape, angularity, and angle of repose; (2) water velocity, depth, shear stress, and flow direction near the riprap; and (3) the slope of the embankment or cover to be protected. Through the proper sizing and placement of riprap on any impoundment cover, rill and gully erosion can be minimized to ensure long term stabilization.

The primary failure mechanism of concern is the removal of material from the impoundment due to shear forces developed by water flowing parallel and/or adjacent to the cover as described by Nelson et al. (1983). One purpose of the cover is to expedite the removal of precipitation and tributary waters away from the cover to minimize seepage and percolation. However, when surface waters are not properly managed, extreme erosion may result and endanger the impoundment stability. For example, slopes are often designed and constructed to develop sheet flow conditions. After many years of exposure, sheet and rill erosion, and localized settlement, the hydraulic conditions have significantly altered causing flows to merge or concentrate into drainage channels. The greater the concentration of flow into the drainage channels, the greater the erosion potential.

4.2.1 Zone Protection

The design requirements for placing riprap rock on a cover vary depending upon cover location. It is suggested that four areas exist on the cover in which different failure mechanisms can result from tributary drainage. The four areas or zones of concern are presented in Figure 4.6 and include:

1. Zone I: This zone is considered the toe-of-the-slope of the reclaimed impoundment. The riprap protecting the slope toe must be sized to stabilize the slope due to flooding in the major watersheds and dissipate energy as the flow transitions from the impoundment slope into the natural terrain. Zone I is considered a zone of frequent saturation.

2. Zone II: This is the area along the side slope which remains in the major watershed flood plain (PMF). The rock protection must resist not only the flow off the cover, but also floods. The

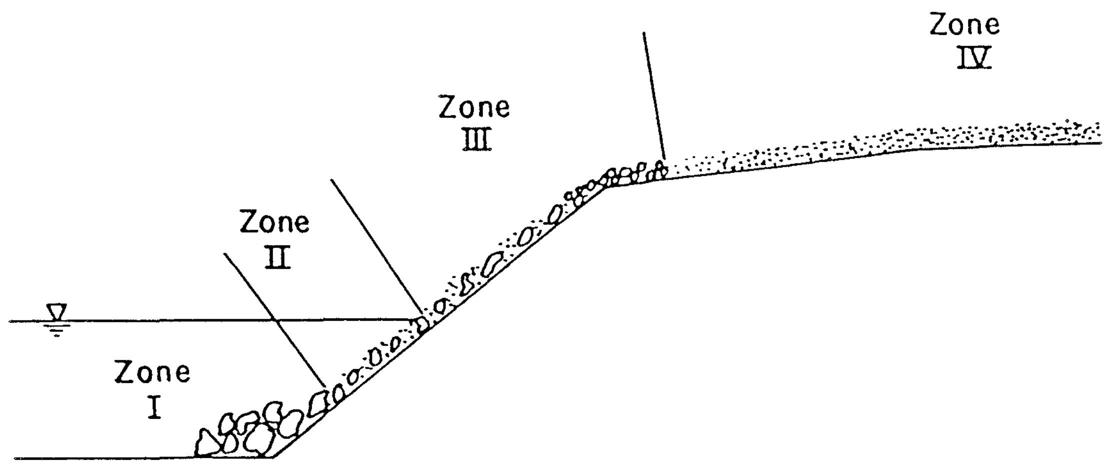


Fig. 4.6. Zones of a reclaimed impoundment requiring riprap protection.

riprap must serve as embankment protection similar to river and canal banks. Zone II is considered a zone of occasional saturation.

3. Zone III: Riprap should be designed to protect steep slopes and embankments from potential high overtopping velocities and excessive erosion. Flows in Zone III are derived from tributary drainage and direct runoff from the reclaimed site. Zone III is considered a seldom saturated zone.

4. Zone IV: Rock protection for Zone IV is generally designed for flows from mild slopes. Zone IV will usually be characterized by sheet flow with low flow velocities. Zone IV is considered a zone of seldom saturation.

Since the rock protection requirements are significantly different on various locations on the cover, it should be apparent that each riprap design procedure available was formulated to address a specific application. Since a single riprap design procedure does not necessarily meet all of the cover protection requirements, recommendations will be made indicating which zone(s) each riprap design procedure best addresses.

Because the frequency of wetting or saturation varies by zone, the durability requirements of the riprap may vary by zone. The concept of durability and oversizing will be addressed in Chapter 6 of this report.

4.2.2 Design Procedures

Presently, several methods are available to assist the designer in determining the appropriate rock size for protection of impoundment covers, embankments and unprotected slopes from the impact of drainage waters. Alternative riprap design methods summarized herein are

1. Safety Factors Method
2. The Stephenson Method
3. Corps of Engineers Method
4. The U.S. Bureau of Reclamation Method

These riprap design procedures are but examples of the many methods available.

4.2.2.1 Safety Factors Method

The Safety Factors Method (Richardson et al., 1975) for sizing rock riprap is quite versatile in that it allows the designer to evaluate rock stability from flow parallel to the cover and adjacent to the cover. The Safety Factors Method can be used by assuming a rock size and then calculating the safety factor (S.F.) or allowing the designer to determine a S.F. and then computing the corresponding rock size. If the S.F. is greater than unity, the riprap is considered safe from failure; if the S.F. is unity, the rock is at the condition of incipient motion; and if S.F. is less than unity, the riprap will fail.

where d_{50} is the mean rock size in feet. A graphical representation for determining n is presented in Figures 4.12 and 4.13. However, these values were developed for uniform flow condition over submerged riprap. When overtopping flows on steep slopes begin to cascade, n values will increase and may range from 0.07 to 0.09 or higher. (Abt and Ruff, 1985 and COE, 1970).

Table 4.2. Manning Coefficient, n.

Channel Material	Manning Coefficient, n
Fine sand, colloidal	0.020
Sandy loam, non-colloidal	0.020
Silt loam, non-colloidal	0.020
Alluvial silts, non-colloidal	0.020
Ordinary firm loam	0.020
Volcanic ash	0.020
Stiff clay, very colloidal	0.025
Alluvial silts, colloidal	0.025
Shales and hardpans	0.025
Fine gravel	0.020
Graded loam to cobbles, non-colloidal	0.030
Graded silts to cobbles, colloidal	0.030
Coarse gravel, non-colloidal	0.025
Cobbles and shingles	0.035

Source: Morris and Wiggert, 1972.

4.8 COVER EROSION RESISTANCE EVALUATION

The cover design should be evaluated to determine if the unprotected slopes(s) can withstand overland or sheet flow with a minimum of erosion. Based upon the site-specific cover and precipitation parameters, the design sheet flow velocity should be estimated. A comparison of the design flow velocity with the cover permissible flow velocity can be performed. Furthermore, the design velocity can be used to determine the sediment discharge using the Universal Soil Loss Equation (Chapter 5) and for sizing stone protection (Section 4.2).

The design velocity will usually be determined from the peak discharge generated from the Probable Maximum Flood (PMF). The PMF can be estimated by

(a) Using computer models, i.e., HEC-1 (COE, 1974), that are widely accepted by the engineering profession.

(b) Applying the Rational Method for tributary areas that are less than approximately one square mile in area.

The Rational formula is commonly expressed as

$$Q = CiA \tag{4.42}$$

where Q is the maximum or design discharge in cfs, C is a runoff coefficient dependent upon the characterization of the drainage basin, i is the rainfall intensity expressed in inches per hour and A is the tributary area expressed in acres. When a unit width approach is taken, the area A_W is the slope(s) length times the unit width. Therefore, Equation 4.42 would be presented as

$$q = CiA_W \tag{4.43}$$

for a unit width analysis.

4.8.1 Runoff Coefficient

The runoff coefficient, C, is related to the climatic conditions and type of terrain characteristic of the watershed including soil materials, permeability and storage potential. Values of the coefficient C are presented in Table 4.4 (Lindsley et al., 1958), Table 4.5 (Chow, 1964), and Table 4.6 (ASCE, 1970 and Seelye, 1960).

Table 4.4. Values of Coefficient C.

Type Area	Value of C
Flat cultivated land, open sandy soil	0.20
Rolling cultivated land, clay-loam soil	0.50
Hill land, forested, clay loam soil	0.50
Steep, impervious slope	0.95

Source: Lindsley, et al, 1958.

The selection of a coefficient value requires considerable judgment as it is a tangible aspect of using the rational formula. It is recommended that a conservative value of C be applied for PMF estimation since infiltration and storage comprise a low percentage of the runoff. Furthermore, the C values presented were derived for storms of 5-100 year frequencies. Therefore, less frequent, higher intensity storms will require the use of a higher C value (Chow, 1964). It is recommended that a runoff coefficient of 1.0 be used for PMF applications in very small watersheds since the effects of localized storage and infiltration will be small.

Table 4.5. Values of C for Use in Rational Formula.

Soil Type	Watershed Cover		
	Cultivated	Pasture	Woodlands
With above-average infiltration rates; usually sandy or gravelly	0.20	0.15	0.10
With average infiltration rates; no clay pans; loams and similar soils	0.40	0.35	0.30
With below-average infiltration rates; heavy clay soils or soils with a clay pan near the surface; shallow soils above impervious rock	0.50	0.45	0.40

Source: Chow, 1964.

4.8.2 Rainfall Intensity

In order to determine the rainfall intensity, i, the time of concentration, t, must be estimated. The time of concentration can be approximated by:

(a) Applying one of the many accepted empirical formulae such as

$$t_c = 0.00013 \frac{L^{0.77}}{S^{0.385}} \tag{4.44}$$

where L is the length of the basin in feet measured along the watercourse from the upper end of the watercourse to the drainage basin outlet and S is the average slope of the basin. Time of concentration is expressed in hours. This procedure is not applicable to rock covered slopes. This expression was

Table 4.6. Values of runoff coefficient C.

Character of Surface	Runoff Coefficients	
	Range	Recommended
Pavement--asphalt or concrete	0.70-0.95	0.90
Gravel, from clean and loose to clayey and compact	0.25-0.70	0.50
Roofs	0.70-0.95	0.90
Lawns (irrigated) sandy soil		
Flat, 2 percent	0.05-0.15	0.10
Average, 2 to 7 percent	0.15-0.20	0.17
Steep, 7 percent or more	0.20-0.30	0.25
Lawns (irrigated) heavy soil		
Flat, 2 percent	0.13-0.17	0.15
Average, 2 to 7 percent	0.18-0.22	0.20
Steep, 7 percent	0.25-0.35	0.30
Pasture and non-irrigated lawns		
Sand		
Bare	0.15-0.50	0.30
Light vegetation	0.10-0.40	0.25
Loam		
Bare	0.20-0.60	0.40
Light vegetation	0.10-0.45	0.30
Clay		
Bare	0.30-0.75	0.50
Light vegetation	0.20-0.60	0.40
Composite areas		
Urban		
Single-family, 4-6 units/acre	0.25-0.50	0.40
Multi-family, >6 units/acre	0.50-0.75	0.60
Rural (mostly non-irrigated lawn area)		
<1/2 acre - 1 acre	0.20-0.50	0.35
1 acre - 3 acres	0.15-0.50	0.30
Industrial		
Light	0.50-0.80	0.65
Heavy	0.60-0.90	0.75
Business		
Downtown	0.70-0.95	0.85
Neighborhood	0.50-0.70	0.60
Parks	0.10-0.40	0.20

Source: ASCE, 1970 and Seelye, 1960.

designed for and applicable to small drainage basins (Kirpich, 1940).

(b) Using the Soil Conservation Service (SCS) Triangular Hydrograph Theory (DOI, 1977), the time of concentration is

$$t_c = \left(\frac{11.9\ L^3}{H}\right)^{0.385} \qquad (4.45)$$

See USNRC (pg D-3) "Final Staff Technical Position Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites" (1990)

where L is the length (miles) of the longest watercourse from the point of interest to the tributary divide, H is the difference in elevation (feet) between the point of interest and the tributary divide. The time of concentration will be expressed in hours. The SCS procedure is most applicable to drainage basins of at least 10 square miles.

Once the rainfall duration or time of concentration is determined, the rainfall depth can be computed based on the PMP intensity values estimated in Section 2.1.2.

4.8.3 Tributary Area

The tributary area may be expressed in a unit width format for design of rock protection on an embankment. Therefore, the area is the length of the longest expected or measured water course multiplied by the unit width. This procedure is primarily applicable to Zones I, II, and III and is not applicable for drainage ditch design. It should be noted that a unit width approach to drainage and diversion ditch design is not effective. Ditch design requires an entire basin analysis in which a composite inflow hydrograph is determined and is routed along the channel. From the inflow hydrograph, water surface profiles (i.e., HEC-2) can be estimated to determine flow depth and velocities for riprap design (COE, 1982).

4.8.4 Sheet Flow Velocity

The design velocity for sheet flow on an embankment slope can be estimated by solving the Manning formula presented in Equation 4.39. It is assumed that the hydraulic radius, R, is approximately equal to the flow depth, y, and that the design discharge is equal to that estimated by the Rational Method. Therefore, the depth of flow is

$$y = \left[\frac{Qn}{1.486\ S^{1/2}}\right]^{3/5} \qquad (4.46)$$

where Q is the discharge, S is the slope, and n is the Manning coefficient.

Therefore, the design velocity can be estimated as

$$V_{Design} = Q/A \text{ (feet/sec)} \tag{4.47}$$

where A is the cross-sectional area of flow.

4.9 FLOW CONCENTRATIONS

Despite the extensive efforts of the impoundment reclamation designer, reviewer, contractor and inspector, the topographic features of the cover will alter over time without continual maintenance (Powledge and Dodge, 1985). Cover modifications will result from differential settlement, collapsing soils, marginal quality control in cover placement, erosion, major hydrologic events and monitoring disturbance. Because of these unpredictable and generally uncontrollable events, tributary drainage areas evolve that were not originally designed or constructed. The result is that the peak discharge and volume of runoff exceed design levels and increase the erosion potential.

Abt and Ruff (1985) conducted a series of flume experiments on a 1V:5H prototype embankment protected by riprap with median rock sizes of 2 inches to 6 inches in diameter. It was observd that 2-4 inch diameter riprap were highly susceptible to sheet flows converging along the face of the embankment into channels. The discharge in the channel(s) was compared to the total discharge over the embankment by

$$CF = \frac{1}{1 - (Q_c - Q)} \tag{4.48}$$

where CF is the concentration factor, Q_c is the discharge in the channel and Q is the total discharge over the embankment. The concentration factors ranged from 1.1 to 3.2 where flows were less than the failure discharge. These preliminary results indicate that riprap designed for sheet flow conditions may be subjected to flow channelizations that concentrate 3 times the discharge in a single location.

The peak discharge along a crest or at a design point is a function of the amount of precipitation, the tributary drainage area, the slope of the drainage basin, the basin contouring, the cover material and cover protection. Any modification in one or more of these parameters can impact the outlet peak discharge. The cover design must account for these potential changes in the form of a concentration or safety factor. Therefore, a flow concentration factor may be incorporated into the design process to adequately evaluate the soil resistance to erosion, to adequately select and evaluate alternative protective measures and to size riprap when warranted.

It is difficult to accurately predict the value of the flow concentration factor since limited information is currently available to substantiate design limits. However, it is reasonable to assume that values between 2 and 3 are attainable with only a slight evolutionary change in cover. Unless it can be shown that design procedures such as overbuilding can compensate for differential settlement, it is recommended that a conservative concentration factor be used until additional research can justify a more reasonable range of values.

To incorporate the flow concentration factor into the stone sizing procedure of any riprap design method, multiply the design peak discharge by the flow concentration factor. All subsequent computations, i.e., velocity and depth estimate, stone size determination, etc., will reflect the influence of the flow concentration.

4.10 PERMISSIBLE VELOCITIES

Evaluation of proposed reclamation alternatives should include an analysis of the critical erosion potential of the cover material. Erosion potential can be determined based upon the properties of the reclamation materials as well as the degree of compaction in which the material is placed. The permissible velocity approach consists of specifying a velocity criterion that will not erode the cover or channel and will prevent scour. A comparison of the actual or design flow velocities to the permissible velocities associated with overland flows, sheetflows or channel flows determines the erosion potential. When the design flow velocity meets or exceeds the permissible velocity, cover protection should be considered.

The permissible velocity values presented were developed from experiments performed primarily in canals and stream beds. Therefore, the following permissible velocities should provide a conservative estimate for evaluating the erosion resistance of the reclaimed covers over long term periods. In cases where a range of permissible velocities are presented, it is recommended that the lower velocity be used for determining erosion potential.

A series of permissible maximum canal velocities was developed by Fortier and Scobey (1926) and adapted by Lane (1955). The maximum permissible velocities presented in Table 4.7 are applicable to colloidal silts. These velocity values were developed for channels without sinuosity. Lane recommended a reduction of the velocities in Table 4.7 by 13 percent if the canal/channel is moderately sinuous. The maximum allowable velocities for sandy-based materials are given in Table 4.8. Table 4.9 provides limiting velocities for cohesive materials according to compactness for materials with less than 50 percent sand content. The Soil Conservation Service maximum permissible velocities (SCS, 1984) for well maintained grass covers are presented in Table 4.10.

It is important to recognize that limited information is available pertaining to permissible velocities on covers under sheet flow conditions.

Table 4.7. Maximum permissible velocities in erodible channels.

Channel Material	Water Transporting Colloidal Silts v (ft/sec)
Fine sand, colloidal	2.50
Sandy loam, non-colloidal	2.50
Silty loam, non-colloidal	3.00
Alluvial silts, non-colloidal	3.50
Firm loam	3.50
Volcanic ash	3.50
Stiff clay, colloidal	5.00
Alluvial silts, colloidal	5.00
Shales and hardpans	6.00
Fine gravel	5.00
Graded loam to cobbles, non-colloidal	5.00
Graded silts to cobble, colloidal	5.50
Coarse gravel, non-colloidal	6.00
Cobbles and shingles	5.50

Source: Lane 1955.

Table 4.8. Maximum allowable velocities in sand-based material.

Material	Velocity (ft/sec)
Very light sand of quicksand character	0.75 to 1.00
Very light loose sand	1.00 to 1.50
Coarse sand to light sandy soil	1.50 to 2.00
Sandy soil	2.00 to 2.50
Sandy loam	2.50 to 2.75
Average loam, alluvial soil, volcanic ash	2.75 to 3.00
Firm loam, clay loam	3.00 to 3.75
Stiff clay soil, gravel soil	4.00 to 5.00
Coarse gravel, cobbles and shingles	5.00 to 6.00
Conglomerate, cemented gravel, soft slate, tough hardpan, soft sedimentary rock	6.00 to 8.00

Source: Lane, 1955.

Therefore, the permissible velocities developed for channels is usually extended to overland flow situations. When design velocities reach or exceed those indicated in Tables 4.7 through 4.10, protection is warranted.

Table 4.9. Limiting Velocities in Cohesive Materials.

	Compactness of Bed			
	Loose	Fairly Compact	Compact	Very Compact
Principle Cohesive Material	Velocity (ft/sec)	Velocity (ft/sec)	Velocity (ft/sec)	Velocity (ft/sec)
Sandy clay	1.48	2.95	4.26	5.90
Heavy clayey soils	1.31	2.79	4.10	5.58
Clays	1.15	2.62	3.94	5.41
Lean clayey soils	1.05	2.30	3.44	4.43

Source: Lane, 1955.

The materials presented in Tables 4.7 through 4.9 can be referenced to the Unified Soil Classification System as presented by Wagner (1957). An engineering analysis of the cover material can provide an approximation of the permissible velocities that the alternative cover materials may withstand without supplemental protection.

4.11 PERMISSIBLE VELOCITY EXAMPLE

A tailings disposal site located in the northwest corner of New Mexico has prepared a reclamation plan for review. The reclamation plan indicates that a 10 foot thick cap will be placed atop the tailings at a slope of 2.4% with a compaction of 95% of optimum. The cap will be graded as shown in Figure 4.14 and shall transition into side slopes of 1V:10H. It is proposed that the cap will be composed of a sandy clay with a coarse gravel cover. Along the crest, a 12 inch thick layer of riprap will be placed for at least 8 feet upslope and downslope of the crest to stabilize the transition. The riprap will have a median stone size of 6 inches. The gravel cover will have a median rock size of 1.5 inches. The design reviewer must verify that the gravel cover will resist the potential velocities that may result on the cap.

In order to assess the stabilization of the cap against erosion due to overland flow, information provided in Sections 4.6 through 4.10 of this report must be utilized. One alternative means of reviewing the design is presented in the following analysis.

4.11.1 Estimation of Peak Runoff

The peak runoff can be estimated using the Rational formula presented in Equation 4.43. The three components of the Rational formula that require consideration are: the runoff coefficient, C; the rainfall intensity, i; and the tributary area, A.

The runoff coefficient can be estimated by examining Tables 4.4 through 4.6. Since the cap will be composed of a compacted clay, the infiltration and localized storage will be low. The peak runoff is a direct function of the estimated localized PMF. Therefore, a reasonable C value is 1.0.

The rainfall intensity can be estimated by determining the 1-hr, 1-mi^2 local storm PMP value and adjusting the rainfall depth in accordance with the percentages presented in Table 2.1. For northwest New Mexico, the 1-hr, 1-mi^2 PMP is estimated to be 9.5 inches after the appropriate elevation and area adjustments are performed.

The time of concentration, t_c, should be estimated. Using Equation 4.44, the t_c can be estimated where the longest flow path is approximately 450 feet as

$$t_c = 0.00013 \frac{(450)^{0.77}}{(0.024)^{0.385}} \qquad (4.49)$$

and

$$t_c = 0.06 \text{ hrs} = 3.62 \text{ minutes} \qquad (4.50)$$

The rainfall depth for variable rainfall durations can be estimated using the values presented in Table 2.1 which are applicable to northwest New Mexico. Since the time of concentration is 3.6 minutes, the percent of the 1-hr PMP can be interpolated to be approximately 35 percent. The rainfall depth is computed using Equation 2.1 to be

$$\text{Rainfall depth} = (0.35) \times 9.5 \text{ inch} = 3.33 \text{ inches} \qquad (4.51)$$

A conservative estimate of the rainfall intensity is determined by applying Equation 2.2.

$$i = 3.33 \text{ inches} \times \frac{60}{3.6} = 55.5 \text{ inches/hr} \quad (4.52)$$

The tributary area, A, can be estimated using a unit width approach presented in Section 4.8. Since the longest flow path is 450 feet with a unit width of one foot, the tributary area is 450 square feet. The tributary area can be converted to acres by dividing by 43,560 square feet/acre resulting in an area of 0.0103 acres.

The peak sheet flow unit discharge at the transition can be computed by using the Rational formula presented in Equation 4.43.

$$q = (1.0)\ (55.5)\ (0.0103) = 0.57 \text{ cfs} \quad (4.53)$$

4.11.2 Sheet Flow Velocity

The sheet flow design velocity can be estimated by first determining the depth of flow. The depth of flow, y, can be calculated using Equation 4.46. However, the Manning surface roughness coefficient, n, must be determined. From Equation 4.41, the Manning n value can be calculated as

$n = 0.0395 (d_{50})^{1/6}$

$$n = 0.0395\ (0.125)^{1/6} = 0.028 \quad (4.54)$$

The depth of flow is then computed to be

$$y = \left[\frac{(0.57)\ 0.028}{1.486\ (0.024)^{1/2}}\right]^{3/5} = 0.202 \text{ feet} \quad (4.55)$$

or

$$y = (0.202 \text{ ft})\ (12 \text{ in/ft}) = 2.42 \text{ inches} \quad (4.56)$$

The design sheet flow velocity is calculated using Equation 4.47.

$$V = \frac{0.57}{(1.0)(0.20)} = 2.82 \text{ feet/sec} \quad (4.57)$$

where 0.57 is the unit discharge, 1.0 is the width of flow in feet and 0.20 is the depth of flow in feet. It should be noted that the flow concentration factor was not incorporated into this computation.

4.11.3 Cover Permissible Velocity

The permissible velocity for the clay cap covered with gravel has been determined to be 5.0-6.0 feet/sec as presented in Table 4.8. Since the design sheet flow velocity was calculated to be 2.9 feet/sec, the cover should be able to withstand the design flow.

NUREG/CR-4651
ORNL/TM-10100

Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase I

Manuscript Completed: October 1986
Date Published: May 1987

Prepared by
S. R. Abt, M. S. Khattak, J. D. Nelson, J. F. Ruff,
A. Shaikh, R. J. Wittler, Colorado State University
D. W. Lee, N. E. Hinkle, Oak Ridge National Laboratory

Colorado State University
Fort Collins, CO 80523

Under Contract to:
Oak Ridge National Laboratory
Oak Ridge, TN 37831

Prepared for
Uranium Recovery Field Office
Region IV - Box 25325
U.S. Nuclear Regulatory Commission
Denver, CO 80401
and
Division of Waste Management
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555
NRC FIN A9350

embankments, channel and unprotected slopes from the impact of flowing waters. Four riprap design procedures which will be referenced are:

1. Safety Factors Method (SF)
2. The Stephenson Method (STEPH)
3. The U.S. Army Corps of Engineers Method (COE)
4. The U.S. Bureau of Reclamation Method (USBR)

A summary of each method will be presented.

3.4.1 Safety Factors Method

The Safety Factors Method (Richardson et al., 1975) for sizing riprap allows the designer to evaluate rock stability from flow parallel to the cover and adjacent to the cover. The Safety Factors Method can be used by assuming a stone size and then calculating the safety factor (SF) or allowing the designer to determine a SF and then computing the corresponding stone size. If the SF is greater than unity, the riprap is considered safe from failure; if the SF is unity, the rock is at the condition of incipient motion; and if SF is less than unity, the riprap will fail.

The following equations are provided for riprap placed on a side slope or embankment where the flow has a non-horizontal (downslope) velocity vector. The safety factor, SF, is:

$$SF = \frac{\cos\theta \tan\phi}{\eta' \tan\phi + \sin\theta \cos\beta} \tag{3.5}$$

where

$$\eta' = \eta \left[\frac{[1 + \sin(\lambda + \beta)]}{2} \right] \tag{3.6}$$

$$\eta = \frac{21\ \tau_0}{(G_s - 1)\ \gamma\ D_{50}} \tag{3.7}$$

$$\tau_0 = \gamma\ DS \tag{3.8}$$

and

$$\beta = \tan^{-1} \left[\frac{\cos\lambda}{(2\ \sin\theta)/(\eta \tan\phi) + \sin\lambda} \right] \tag{3.9}$$

The angle, λ, is shown in Figure 3.1 and is the angle between a horizontal line and the velocity vector component measured in the plane of the side slope. The angle, θ, is the side slope angle shown in Figure 3.1 and β is the angle between the vector component of the weight, W_s, directed down the side slope and the direction of particle movement. The angle, ϕ, is the angle of repose of the riprap, τ_0 is the bed shear stress (Simons and Senturk, 1977), D_{50} is the representative stone size, G_s is the specific gravity of the rock, D is the depth of flow, γ is the specific weight of the liquid, S is the slope of the channel, and η' and η are stability numbers. In Figure 3.1, the forces F_l and F_d are the lift and drag forces, and the moment arms of the various forces are indicated by the value e_i as i = 1 through 4. Figure 3.2 illustrates the angle of repose for riprap material sizes.

Riprap is often placed along side slopes where the flow direction is close to horizontal or the angularity of the velocity component with the

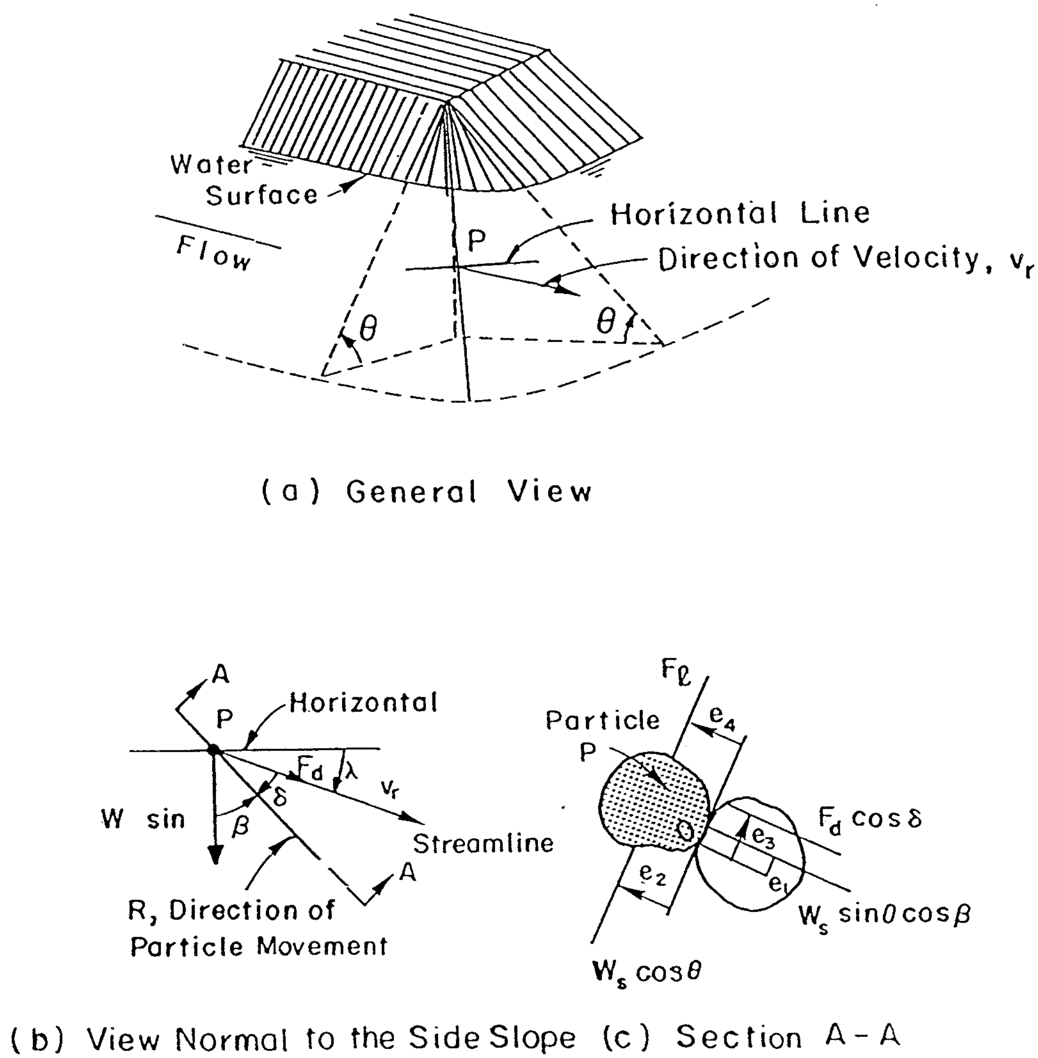


Fig. 3.1. Riprap stability conditions as described in the Safety Factors Method.

horizontal is small (i.e., $\lambda = 0$). For this case, the above equations reduce to:

$$\tan \beta = \frac{\eta \tan \phi}{2 \sin \theta} \quad (3.10)$$

and

$$\eta = \left[\frac{S_m^2 - (SF)^2}{(SF)\ (S_m^2)} \right] \cos \theta \quad (3.11)$$

where

$$S_m = \frac{\tan \phi}{\tan \theta} \quad (3.12)$$

The term S_m is the safety factor of the rock particles against rolling down the slope with no flow. The safety factor, SF, for horizontal flow may be expressed as:

$$SF = \frac{S_m}{2} [S_m^2\, \eta^2 \sec^2 \theta + 4)^{0.5} - S_m\, \eta \sec \theta] \quad (3.13)$$

Riprap may also be placed on the cover or side slope. For a cover sloping in the downstream direction at an angle, α, with the horizontal, the equations reduce to:

$$SF = \frac{\cos \alpha \tan \phi}{\eta \tan \phi \sin \alpha} \quad (3.14)$$

Historic use of the Safety Factors Method has indicated that a minimum SF of 1.5 for non-PMF applications (i.e. 100-year events) provides a side slope with reliable stability and protection (Simons and Senturk, 1977). However, a SF of slightly greater than 1.0 is recommended for PMF or maximum credible flood circumstances. It is recommended that the riprap thickness be a minimum of 1.5 times the D_{50}. Also, a bedding or filter layer should underlay the rock riprap. The filter layer should minimally range from 6 inches to 12 inches in thickness. In cases where the Safety Factors Method is used to design riprap along embankments or slopes steeper than 4H:1V, it is recommended that the toe be firmly stabilized.

3.4.2 Stephenson Method

The Stephenson Method for sizing rockfill to stabilize slopes and embankments is an empirically derived procedure developed for emerging flows (Stephenson, 1979). The procedure is applicable to a relatively even layer of rockfill acting as a resistance to through and surface flow. It is ideally suited for the design and/or evaluation of embankment gradients and rockfill protection for flows parallel to the embankments, cover or slope.

The sizing of the stable stone or rock requires the designer to determine the maximum flow rate per unit width (q), the rockfill porosity (n_p), the acceleration of gravity (g), the relative density of the rock (G_s), the angle of the slope measured from the horizontal (θ), the angle of friction (ϕ), and the empirical factor (C).

The stone or rock size, D_{50}, is expressed by Stephenson as

$$D_{50} = \left[\frac{q(\tan\theta)^{7/6} n_p^{1/6}}{C\, g^{1/2}\, [1-n_p)(G_s-1)\cos\theta\,(\tan\phi - \tan\theta)]^{5/3}} \right]^{2/3} \qquad (3.15)$$

where the factor C varies from 0.22 for gravel and pebbles to 0.27 for crushed granite. The stone size calculated in Equation 3.15 is the representative diameter, D_{50}, at which rock movement is expected for unit discharge, q. The representative median stone diameter (D_{50}), is then multiplied by Oliviers' constant, K, to insure stability. Oliviers' constants are 1.2 for gravel and 1.8 for crushed rock. The rockfill layer should be well graded and at least two times the D_{50} in thickness. A bedding layer or filter should be placed under the rockfill.

The Stephenson Method does not account for uplift of the stones due to emerging flow. This procedure was developed for flow over and through rockfill on steep slopes. Therefore, it is recommended that the Stephenson Method be applied as an embankment stabilization for overflow or sheetflow conditions. Alternative riprap rockfill design procedures should be considered for toe and stream bank stabilization.

3.4.3 U.S. Army Corps of Engineers Method

The U.S. Army Corps of Engineers has developed perhaps the most comprehensive methods and procedures for sizing riprap revetment. Their criteria are based on extensive field experience and practice (COE, 1970 and

SECOND EDITION

ORIGIN OF SEDIMENTARY ROCKS

HARVEY BLATT
University of Oklahoma

GERARD MIDDLETON
McMaster University

RAYMOND MURRAY
University of Montana

Prentice-Hall, Inc., Englewood Cliffs, New Jersey 07632

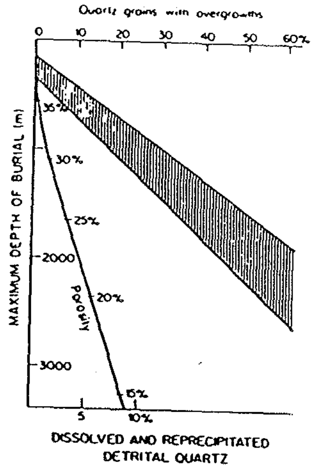


Fig. 12-8 Porosity, burial depth, and abundance of quartz overgrowths in quartz sandstones from the "Dogger beta" (Jurassic), West Germany. For example, at a depth of 1000 m the porosity is 31%, quartz overgrowths form 1% of the rock, and between 19% and 30% of the detrital quartz grains have overgrowths. (From Hans Füchtbauer, 1967, *Proc. 7th World Pet. Cong., Mexico City*, 2, 354. Used by permission of the Elsevier Scientific Pub. Co.)

by retarding pressure solution and the formation of quartz overgrowths. Fluid flow through sandstones may also enhance porosity by dissolving earlier-formed cements or detrital mineral grains.

12.4 PERMEABILITY

Permeability is a measure of the ease with which a fluid flows through a rock. It is defined by an empirical relationship first recognized by the French hydrologist Henri Darcy in 1856 and may be written

$$V = \frac{Q}{A} = k\frac{\Delta p}{\mu l}$$

where V = apparent velocity (cm/s)
Q = discharge (cm^3/s)
A = cross-sectional area (cm^2)
k = permeability (darcies = $cm^2 \times 10^{-8}$)
μ = fluid viscosity (centipoises, gm/cm s $\times 10^{-2}$)
l = distance of flow (cm)
p = pressure (dynes/cm^2); this term consists of both a fluid pressure term and a gravitational acceleration term.

Permeabilities to water of more than 500 darcies have been measured in modern river sands; in ancient rocks permeabilities to air range from a high of several darcies in coarser sandstones to a measured low of 10^{-11} darcy in a shale. The median permeability of petroleum reservoirs is on the order of 0.1 darcy (100 md).

Permeability is normally determined in the laboratory by scaling the side of the cylindrical rock core, removing any oil in the core with a solvent, and forcing air longitudinally through the core. Thus permeabilities ordinarily reported in core analysis refer to the permeability to dry air at atmospheric pressure. The permeability to freshwater, brine, or petroleum may be much less, depending on the mineral composition of the rock, particularly the amount and type of clay minerals it contains (see below). Unfortunately, the accuracy of core analysis for determining permeability is somewhat illusory. When a core is removed from the subsurface, all confining forces are removed and the rock matrix expands in all directions, partially changing the pore radii and fluid flow paths inside the core. Increases in permeability of more than 100% have been documented (Fatt and Davis, 1952). Presumably the percentage increase depends largely on the depth at which the core was taken and on the mineral composition of the core, particularly its content of clay and mica.

Subsurface measurements of permeability can be made by using semiempirical electric logging techniques, but errors of 100% are possible. A better method in use in petroliferous rocks is to determine the output of a well under a known pressure drawdown or to interpret pressure buildup data during a drill-stem test. The drill-stem test has the advantage that it represents the effective permeability of a large volume of rock under *in situ* conditions.

Depositional permeability is greatest in a direction either parallel to the bedding or at a small angle to it because of grain orientations, micaceous foliations produced during deposition of the sediment, and vertical changes in grain size within the rock unit. Johnson and Hughes (1948) examined 33 Devonian oil sands in New York and Pennsylvania and found variations in permeability averaging 30% in the plane of the bedding, with differences being less pronounced in sands of higher permeabilities. Griffiths (1949) observed that sand grains are normally imbricated at a low angle to the bedding and, therefore, planes parallel to the bedding are projections of sections through the individual grains on a plane that lies at varying angles to varying imbrications. Small variations in grain shape would result in large differences on the projection plane. He found greatest permeabilities in three cores at a low angle to the bedding and attributed the result to the existence of grain imbrication in the sandstones. Mast and Potter (1963) studied permeabilities in the bedding plane of 13 Carboniferous sandstones and concluded that variations in permeability as a result of fabric "are extremely small." Clearly it is difficult to generalize about directional permeability beyond the statement that it is least in a direction approximately normal to bedding.

In some units, however, jointing or microfaulting can increase permeability perpendicular to bedding by orders of magnitude (Nelson and Handin, 1977).

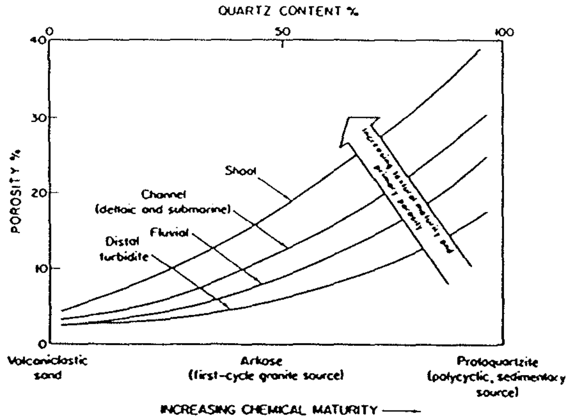


Fig. 12-6 Interrelationships among porosity, mineral composition, and environment of deposition of Jurassic sandstones in the North Sea area. (From R. C. Selley, 1978, *Jour. Geol. Soc.*, 135, 126. Used by permission of the Geological Society.)

in the sand and undercompaction of the mud (Sec. 5.12). The effect of clay mineralogy on compaction of muds can be traced primarily to the presence of smectites or interlayered smectite-illite clays. Smectitic clays contain more water than illitic or kaolinitic clays and resist compaction of the mud.

Burst (1969) has suggested that the compaction of clays proceeds in three main stages. In the first, pore-water and water interlayers beyond two are removed by the action of overburden pressure. At the time of deposition muds may have water contents on the order of 70 to 90%. After a few thousand feet of burial the mud retains only about 30% water by volume, of which 20 to 25% is interlayer water and 5 to 10% is residual pore water. In the second stage, pressure is relatively ineffective as a dehydrating agent. Dehydration proceeds by heating, which removes another 10 to 15% of the water. The second stage begins at temperatures close to 80°C and may be accompanied by diagenetic changes in clay mineralogy. Since this is also the temperature at which organic matter matures to petroleum (Sec. 9.2), is possible that explusion of water during the third stage of clay recrystallization also the cause of the "primary" migration of petroleum from source to reservoir rocks. The third stage of dehydration is also controlled by temperature but apparently is also very slow, requiring tens to hundreds of years to reach completion.

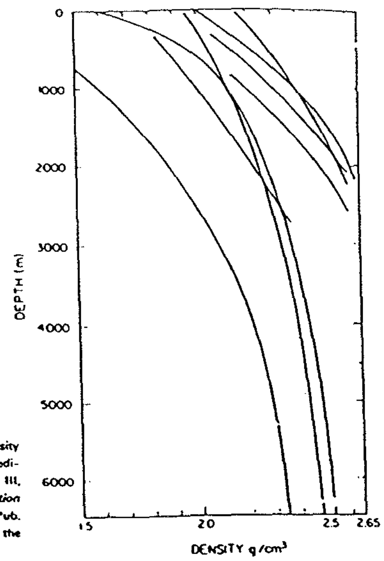


Fig. 12-7 Variation of the bulk density of mudrocks with depth in several sedimentary basins. (From H. H. Rieke, III, and G. V. Chilingar, 1974, *Compaction of Argillaceous Sediments*, Elsevier Pub. Co., p. 34. Used by permission of the Elsevier Scientific Pub. Co.)

Interlayer water is removed completely, leaving only a few percent of pore water in the mudrock.

Authigenesis

Authigenic minerals in sandstones are dominantly calcite and quartz cements but may also be clay minerals (Chap. 9). Authigenesis in both sands and muds is favored by increasing compaction, temperature, and salinity, all of which accompany increased depth of burial. The relationship between burial depth and the formation of secondary growths on detrital quartz grains is illustrated for some Mesozoic sandstones by Füchtbauer (1967) (Fig. 12-8). In some rocks, however, authigenesis may preserve rather then destroy porosity. Lumsden et al. (1971) found that authigenic chlorite coatings on detrital quartz grains in the Spiro and Foster Sands (Pennsylvanian, Oklahoma) preserve the bulk of depositional porosity

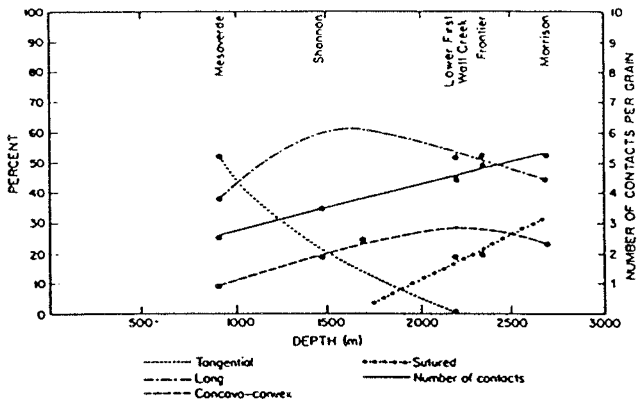


Fig. 12-4 Relationship between depth and type of grain-to-grain contact in thin sections of cores of Mesozoic sandstones in Wyoming. (From J. M. Taylor, 1950, *Amer. Assoc. Pet. Geol. Bull.*, 34, 715. Used by permission of the American Assoc. Petroleum Geologists.)

may have resulted simply from either an increase in percentage of elongate rock fragments with depth or an increase in clay content of the sandstones.

The presence of detrital clay in a sandstone has the same effect as the presence of ductile fragments but increases the rate of compaction. Mud has a very low bearing strength and noticeable compaction of clayey sandstones can occur at depths of only a few meters.

Increased compaction causes a decrease in primary porosity, a feature observed in several field studies. Data relating porosity to burial depth have been collected from large numbers of subsurface cores in different sedimentary basins (Fig. 12-5), and it was found that porosity can decrease either linearly or nonlinearly with depth and at greatly differing rates. Petrographic studies are needed to determine the causes of these differences. The interrelationships among porosity, textural maturity, and mineralogic composition are well illustrated by Selley (1978) in a study of the occurrence of oil in Jurassic sandstones in the North Sea area (Fig. 12-6). Volcaniclastic sands are easily altered chemically during diagenesis to produce fine-grained matrix. Nearly pure quartz sandstones suffer least from diagenetic effects. Arkoses occupy an intermediate position with respect to diagenetic effects. With respect to texture, the situation in the Jurassic rocks is equally clear, with shallow environments being most texturally mature, distal turbidites the least.

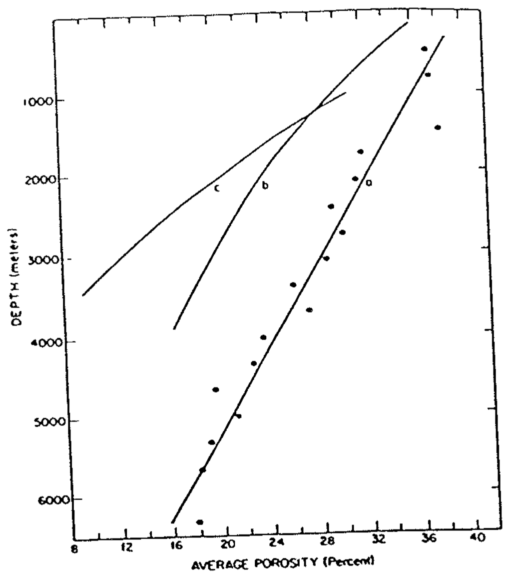


Fig. 12-5 Porosity vs. depth. (a) South Louisiana Tertiary sands; 17,367 samples. (From G. I. Atwater and E. E. Miller, 1965, unpub. ms.; data averaged for each 1000 ft. interval); (b) Great Valley Cretaceous and Tertiary sands; 165 reservoirs. (From D. L. Ziegler, and J. H. Spotts, 1978, *Amer. Assoc. Pet. Geol. Bull.*, 62, 814; (c) Cis-Caucasus, U.S.S.R.; 93 samples. (From B. K. Proshlyakov, 1960, trans. by Assoc. Tech. Serv., Inc., N.J., 1965, p. 3.)

The compaction of muds is considerably more complex than that of sandstones, as Meade (1966) has described. In the early stages, compaction may depend strongly on several factors in addition to depth of burial: grain size, rate of deposition, clay mineralogy, content of organic matter, and geochemical factors (Chapter 11). Variations in these parameters cause wide variations in the amount of compaction suffered by different muds at the same burial depth (Fig. 12-7). Coarser grain size correlates with increased quartz/clay ratio and hence reduced compaction. High rates of deposition can result in the formation of clay "seals" above sand units, which destroy vertical permeability and cause the formation of excess pore pressure

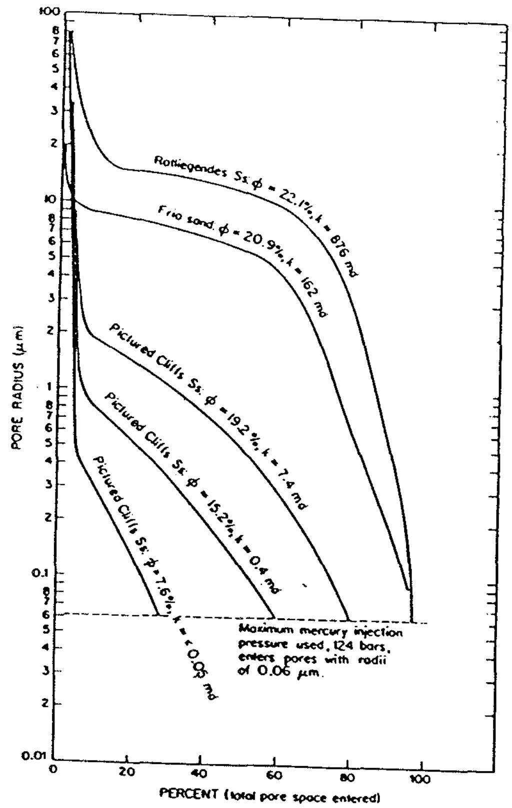


Fig. 12-3 Relationships among total porosity (ϕ), permeability (k), and pore radius of five sandstone cores (courtesy of Amoco Production Company). Total porosity determined by gas expansion. For the three relatively impermeable sandstones, the majority of the pore throat radii are less than 0.5 μm.

to 0.01 μm or less at a depth of 3000 m. These values are an order of magnitude smaller than those typical of sandstones (see Fig. 12-3).

The quantitative significance of the sorting of sand grains on porosity of a sandstone was studied experimentally by Beard and Weyl (1973) for gaussian distributions. Porosity was essentially independent of grain size but decreased sequentially as sorting decreased from 42.4% porosity in extremely well-sorted sands to 27.9% in very poorly sorted sands with no clay matrix. This result seems quite reasonable because smaller grains will lodge between the larger ones. Pryor (1973) found no significant change in the porosity of river, beach, and dune sands with change in standard deviation from 0.3ϕ to 1.6ϕ, but his core samples, unlike those in the Beard and Weyl study, were not homogeneous. Pryor's cores consisted of many thin, individually well-sorted laminae so that although porosity would be excellent, the sediment sorting determined in the laboratory might be good or poor for the core as a unit.

The porosity of a sandstone depends on postdepositional factors as well as those present at the time and site of deposition. As noted, the most important factors during deposition are clay content and the sorting of the sand fraction of the sediment. Of lesser importance are initial grain packing, sand mineralogy, mean grain size (assuming constant sorting), and grain angularity. Important postdepositional or diagenetic factors are degree of compaction and the formation of authigenic minerals.

Compaction

Upon burial, sands compact much less than mudrocks. The lesser compaction of sands results from two factors. First, the average sandstone is composed largely of quartz grains, and these grains are undeformable under most sedimentary conditions. Secondly, the finer particles that predominate in mudrocks are deposited with initially higher water contents and this water is quickly expelled. Many investigators have compacted quartz sands in the laboratory with the result that the thickness of the aggregate has decreased only 10 to 15% due to rearrangement of grains and chipping of grain corners.

The amount of compaction increases significantly with the proportion of ductile rock fragments in the detrital fraction of the sand. Such particles as shale, slate, phyllite, and schist deform easily at shallow depth, decreasing porosity (see below) and thinning the stratigraphic section. This decrease in porosity is noticeable in well logs and was first studied in thin sections of subsurface cores by Taylor (1950). She found that the proportions of the four different types of intergranular contacts changed with depth of burial (Fig. 12-4). Tangential contacts decreased rapidly in abundance with depth, whereas the other three types showed marked increases. Grains were being pushed close together as burial depth increased. Unfortunately, Taylor did not keep a close check on changes in mineral composition with depth; so we cannot be certain how much of the increased closeness of grains was due to plastic deformation of elongate ductile fragments and how much tance. Tortuosity in a sandstone is usually between 2 and 3; in loose sediment it is ıpproximately one-half as large. The greater the tortuosity, the slower the flow of luid through the pore system.

The physical principle on which the mercury injection method is based is that liquids forming contact angles on solid surfaces of more than 90° (i.e., non-wetting fluids) cannot penetrate into small pores unless the injection pressure exceeds the capillary pressure. The higher the injection pressure, the smaller the pores that can be penetrated by the liquid. In circular pores with radius r the surface tension σ acts along the perimeter of the circle with the force $-2\pi r\sigma$. The force counteracting the intrusion of the liquid parallel to the axis of the pore is $-2\pi r\sigma \cos\lambda$, where λ is the angle of contact. The force caused by the injection pressure p is $\pi r^2 p$. For equilibrium, we obtain

$$-2\pi r\sigma \cos\lambda = \pi r^2 p$$

or

$$r = -\frac{2\sigma \cos\lambda}{p}$$

The surface tension of mercury is 484.2 dynes/cm at 25°C, and the angle of contact of mercury on silicate mineral surfaces has been determined experimentally to approximate 141.3°. Using these values,

$$r = \frac{7.6}{p}$$

when pressure is measured in bars and pore radii in micrometers (Fig. 12-2). Using this relationship, mercury injection of a core yields the volume percentage of pore throats of any given size in the rock sample (Fig. 12-3).

The porosity of mudrocks varies over essentially the same range as in sandstones, from zero to about 40%, but the definition of porosity in a mudrock is not as clear-cut as in the coarser-grained rocks. Indeed, the definition and measurement of porosity in mudrocks present problems not encountered in sandstones. In a sandstone composed primarily of quartz and similar minerals, the boundary between pore space and grain is reasonably well defined. For example, if the pore space is filled with water, then this free or movable water represents the porosity. The proportion of adsorbed or bound water is usually negligible because the specific surface of such minerals as quartz is only 1 to 2 m²/g of sediment. (Compare with clay minerals below.) In subsurface studies, logging methods that measure total hydrogen concentration, such as neutron logging, effectively measure the porosity. But mudrocks present a more complex problem. Many of the clay minerals contain water as part of their structure, and this water certainly should be considered part of the solid rather than part of the pore space. In addition, water adsorbed on the surface of the clay flakes normally is not free to move, and vater may form a large percentage of the total water between clay flakes in ıudrock. This situation occurs because the specific surface of clay minerals is very large, on the order of tens of square meters per gram. Within the space between the grains and their adsorbed water, however, there exists free water

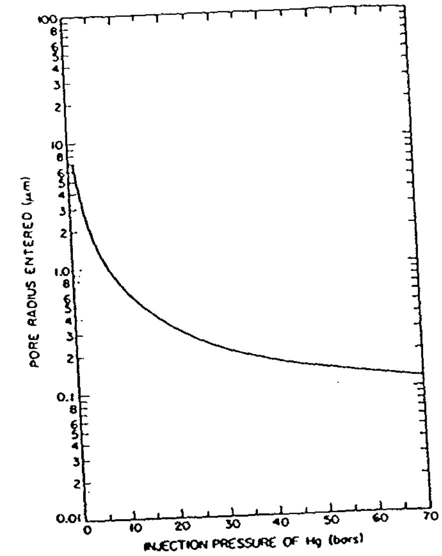


Fig. 12-2 Relationship between injection pressure of mercury into a core and the radii of pore throats that are penetrated.

capable of moving or being easily removed by compaction. Thus when we speak of mudrock porosity, we usually mean the percentage of the total volume of the rock that contains free or easily movable water. It is usually measured by mechanically compacting the rock and measuring the amount of fluid removed or the percentage of volume reduction. These methods are, at best, an approximation of the true pore volume because of the possibility of altering the water content of the clay flakes or the amount of adsorbed water during the analysis.

The critical differences in pore characteristics between sandstones and mudrocks are the sizes and shapes of the pores. Particularly in fissile mudrocks (shales), the clay mineral flakes that form 60% of the mineral grains are oriented in parallel and hence pore spaces are dominantly tabular. Furthermore, because flat flakes can be very closely packed, pore sizes are much smaller. Heling (1970) studied the fabric of Tertiary shales from the Rhinegraben that were buried to depths up to 3400 m. Pore radii decreased from an average of 0.04 μm at a depth of 100 m

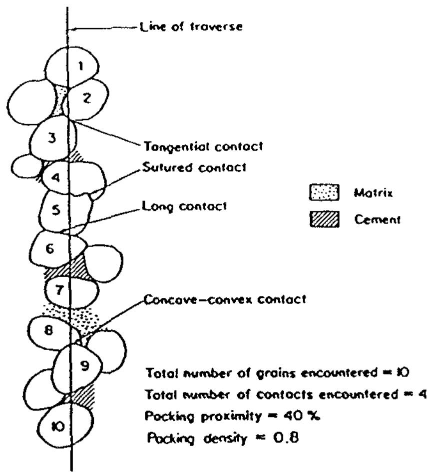


Fig. 12-1 Definition of grain contact types and packing proximity. (After J. M. Taylor, 1950, *Amer. Assoc. Pet. Geol. Bull.*, 34, p. 711, 712, and J. S. Kahn, 1956, *Jour. Geol.*, 64, p. 393).

grain volume; and effective porosity, the ratio of interconnected void volume to total rock volume. In detrital silicate rocks, effective porosity is usually only slightly less than total porosity.

Methods of Measurement

Cores of rocks used for porosity determination are normally cylinders one inch long and one inch in diameter. The porosity can be easily determined by gas expansion, using Boyle's law. Alternatively, the grain density can be assumed (2.65) and the porosity determined by weighing a sample saturated with a fluid of known density. These experimental methods are suitably accurate and are the standards for calibration of all other porosity-determining methods, such as point counts in rock thin sections or subsurface logging techniques. An important point to keep in mind, however, is that the porosity of 13 cm³ of rock may not be representative of a rock unit millions of times larger in volume, particularly because field observations reveal that porosities can vary greatly over small distances with such factors as clay mineral or rock fragment content.

The use of subsurface logging techniques (sonic, density, neutron) can sometimes produce porosity values within 1% of the value obtained on the same rock in a core sample. The advantages of logging methods over core analysis for porosity determination lie in the much larger volume of rock "sampled," perhaps 100 times larger than the laboratory core, and in the fact that the measurement is made *in situ*, before overburden pressure is removed. In addition, there is the matter of cost. Electric logs are made of all wells, but cores are taken in relatively few.

In most sandstones the bulk of pore space has diameters less than the 30 μm thickness of a standard thin section and so is difficult or impossible to detect during examination of the slide unless special techniques are used. The usual technique is to vacuum-impregnate the rock slice with a colored epoxy before thin sectioning so that even extremely narrow pores that intersect the plane of the thin section become visible in uncrossed nicols. This technique, now standard in industry laboratories, also makes it possible to distinguish between pores produced by diagenetic dissolution of detrital grains and pseudopores produced by grain plucking during grinding of the thin section.

Pore Sizes, Geometry, and Measurement

Pores are irregularly shaped cavities in a rock; therefore any definition of their "size" is an approximation based on the measurement technique used to determine it. In some cases, it is possible to vacuum-impregnate a porous rock with either a molten plastic or metal and then dissolve the rock by using suitable reagents to produce a "negative image" of the rock—that is, its three-dimensional pore network (Swanson, 1979). This technique, although useful for some research purposes, is impractical as a standard method.

The distribution of pore sizes in a rock sample is determined generally by injection of mercury into the rock. The sizes of pores determined in this way are actually the sizes of the pore "throats" or narrow connections between large pores. It is the sizes of the throats that control the flow of fluid through rocks, whether the flow is of mercury during measurement of porosity or is water, petroleum, or natural gas in the subsurface. One deficiency of the mercury injection technique is that if a large pore, such as a vug, is entered by fluid through a narrow throat, the large vug will be included within the volume of pore space represented by the throat size. A second deficiency is that not all pores can be invaded by the mercury because they may be shielded by other smaller pores whose displacement pressure is not exceeded.

The individual pore may be tubular like a capillary tube; or it may be nodular and feather out into the bounding constrictions between nodules; or it may be a thin, intercrystalline tabular opening that is 50 to 100 times as wide as it is thick. The wall of the pore may be clean quartz, feldspar, or calcite; or it may be coated with clay mineral particles, platey accessory minerals, or rock fragments. The crookedness of the pore pattern, called the *tortuosity*, is the ratio between the distance between two points by way of the connected pores and the straight-line dis-

CHAPTER 12

POROSITY AND PERMEABILITY OF DETRITAL ROCKS

12.1 INTRODUCTION

The porosity and permeability of sandstones and mudrocks have been generally neglected by academic geologists. Most of our knowledge in this area comes from the petroleum industry as part of its effort to locate reserves of oil and gas. It is strange that few geologists outside of industry have investigated the porosities and permeabilities of detrital rocks, for these variables control most diagenetic processes in rocks. Without adequate permeability to water there can be little cementation of sandstones, diagenetic alteration of heavy minerals, conversion of smectite to illite, or the myriad of other processes that affect rock after burial. Pore space and permeability are basic aspects of rock fabric and should be studied as a normal part of a petrologic investigation.

12.2 FABRIC

The term *fabric* is reserved for "the manner of mutual arrangement in space of the components of a rock body and of the boundaries between these components" (*International Tectonics Dictionary*). It thus includes both the packing

and orientation of grains. Grain packing strongly affects both porosity and permeability and grain orientation affects the permeability (Sec. 12.4).

The least-studied aspect of fabric is *packing*, "the spacing or density pattern of mineral grains in a rock" (AGI Glossary). The meaning of packing and its distinction from other aspects of fabric, such as orientation, is most clearly seen for the case of a sediment composed of perfect spheres uniform in size. Even in this highly idealized case it has been shown that there are six different systematic ways of arranging the spheres so that each sphere is in contact with four or more adjacent spheres and there are no vacant positions. The arrangements vary from the "loosest" cubic packing with a porosity of 47.6% to the "tightest" rhombohedral packing with a porosity of 26.0%. The six regular packings do not exhaust the number of ways that spheres may, in fact, be packed because in nature an infinite number of combinations of the six and of "random" packings may also be developed.

Kahn (1956) devised two numerical measures for use in thin section studies.

1. The *packing density* is the ratio of the sum of the lengths of grain intercepts to the total length of the traverse across the thin section. It is a measure of the porosity of a cement-and matrix-free sand or of the "matrix-cement-free porosity" of a sandstone that has some matrix and cement.
2. The *packing proximity* is the ratio of the number of grain-to-grain contacts (encountered in a traverse across the thin section) to the total number of contacts of all kinds encountered in the same traverse (Fig. 12-1). If the grains have only small areas of contact with each other, most of the contacts observed in a thin section will be contacts between a grain and matrix or cement; so the packing proximity will be small. In a rock in which there has been compaction without the introduction of much cement, most of the grain contacts observed will be grain-to-grain contacts and the packing proximity will be large.

The type of contact between grains can also be studied in thin section. In the ideal case of packed spheres, the only observed contacts between grains would be tangential ones. But in the case of nonspherical grains or where compaction has taken place, three other types of contacts can be observed (Taylor, 1950). The four possible types of contacts are (a) tangential, (b) long—that is, a contact that appears as a straight line in the plane of section, (c) concavoconvex, and (d) sutured. The frequency of concavoconvex and sutured contacts relative to that of other types of contacts has been used as a measure of the intensity of compaction of sands.

12.3. POROSITY

Several terms are widely used to indicate the amount of pore space in a rock. The most common are porosity, the ratio of void volume to total rock volume (multiplied by 100 to form a percentage); void ratio, the ratio of pore volume to

APPENDIX G

Slope Stability

PURPOSE:

Stability Analysis of the Side Slopes of the Cover

The purpose of this calculation brief is to evaluate stability of the side slopes of the cover for the uranium tailings impoundments. The sides of the covers are sloped at 5H:1V. From the old drawings as published by UMETCO (section B-B), the side slope for Cell 4 is the tallest. Also, along the southern section of Cell 4, the ground elevation drops rapidly. Hence the side slopes of the cover located along the southern side of Cell 4 are assumed to be critical and considered for stability analysis.

METHODOLOGY:

Static and pseudostatic slope stability analyses have been performed for the slope geometry as shown in Figure 1. The limit equilibrium slope stability code GSLOPE, developed by MITRE Software Corporation has been used for these analyes. The Bishop's method of slices has been applied.

Geometry and Material Properties

Along the southern end of Cell 4, the topography drops at a rate of approximately 5.5% (Figure 2). The material properties as provided by Dames and Moore, 1978, have been used for these analyses. The material properties have been listed in Table 1, below.

Material No.	Type of Material	Unit weight, γ (pcf)	Cohesion, c (psf)	Angle of friction, ϕ (degrees)
1	Earthfill	123	0	30
2	Tailings	62.4	0	0
3	Dike	123	0	30
4	Foundation	120	0	28
5	Bedrock	130	10,000	45

Table 1: Material Properties

The surface of the bedrock has been determined from the bore-logs as supplied by Chen and Associates, 1978. But as this bedrock surface almost coincides with that of the foundation, assuming the bedrock layer to be about 10 ft. below the lowest point of the foundation surface, will give conservative results. Thus, for the stability analysis, the surface of competent bedrock has been assumed to be at an elevation of +5540 ft. above mean sea level (MSL).

Factor of Safety and Horizontal Acceleration required for analysis:
A factor of safety of 1.5 and 1.0 are respectively acceptable for static and pseudostatic analyses. Pseudostatic slope stability analysis has been performed for a maximum seismic coefficient of 0.1g.

RESULTS:

Results of the stability analyses have been presented in this calculation document.
Results for Static case: For static analysis, the maximum Factor of Safety calculated is 2.91 (>1.5).
Results for Pseudostatic case: For pseudostatic analysis, the maximum Factor of Safety calculated is 1.903 (>1.0) for a ground acceleration of 0.1g.

Hence the side slopes are stable.

REFERENCE:

a) Chen and Associates, Inc., 1978. Soil Property Study, Earth Lined Tailings Retention Cells, White Mesa Uranium Project, Blanding, Utah.

b) Dames and Moore, 1978. Site Selection and Design Study - Tailing Retention and Mill Facilities, White Mesa Uranium Project, January 17, 1978.

c) "GSLOPE Limit Equilibrium Slope Stability Analysis", Mitre Software Corporation, Alberta, Canada

RESULTS OF RUN BY "GSLOPE" ANALYSIS

Material	Unit Wt pcf	C psf	Phi deg	Piezo Surf.	Ru
Earthfill	123	0	30	0	0
Tailings	62.4	0	0	0	0
Dike	123	0	30	0	0
Foundation	120	0	28	0	0
Bedrock	130	10000	45	0	0

Titan Environmental - Bozeman MT

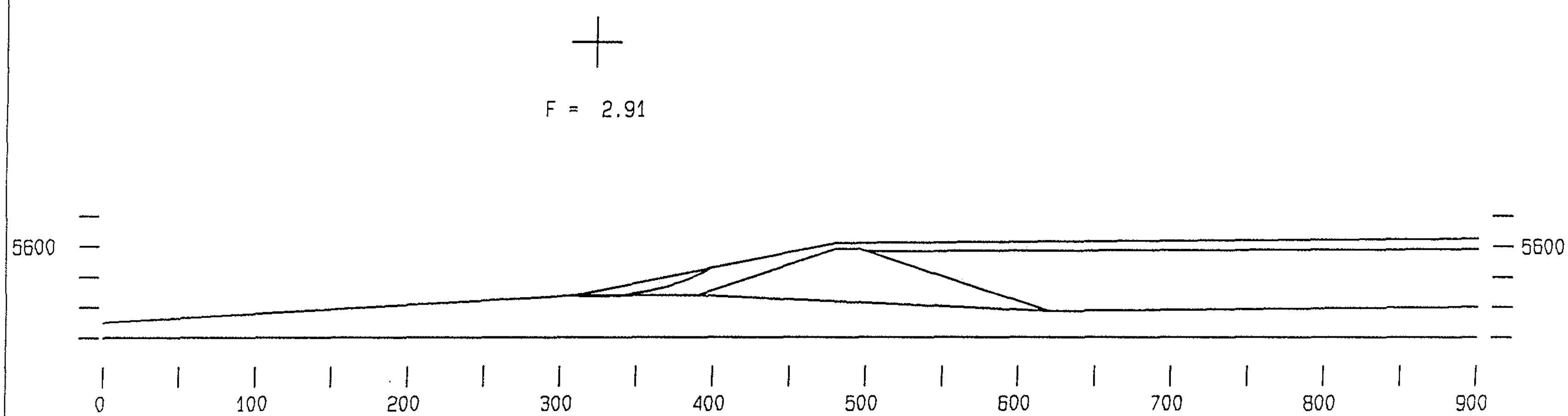
6111.001

EFN White Mesa Slope Stability

7/1996

Static Analysis

WHTMESA1.GSL



DATA FILE NAME..... C:\STABLITY\GSLOPE\WHTMESA1.GSL

Job No.	6111.001
le	EFN White Mesa Slope Stability
Date	7/1996
Label A	Static Analysis
Label B	

Max Slice Width	10
Set Neg. Normals to zero	Y
No. of Materials	5
Seismic Acceleration	0
External Forces	0
Piezometric Surfaces	0
Unit Wt. of Pore Fluid	62.4

Material	Unit Wt	Cohesion	Friction Angle	Piezo Surface	Ru Value
# 1 -Earthfill	123	0	30	0	0
# 2 -Tailings	62.4	0	0	0	0
# 3 -Dike	123	0	30	0	0
# 4 -Foundation	120	0	28	0	0
# 5 -Bedrock	130	10000	45	0	0

Upper Surface of Material # 1 (Earthfill)

X-Coord	Y-Coord
0	5550.5
310	5568
480	5602
900	5605

Upper Surface of Material # 2 (Tailings)

X-Coord	Y-Coord
0	5550.5
310	5568
390	5568
480	5598
495	5598
500	5596.5
900	5598

Upper Surface of Material # 3 (Dike)

X-Coord	Y-Coord
0	5550.5
[illegible]	5568
390	5568
480	5598
495	5598

500	5596.5
620	5557.5
900	5560

Upper Surface of Material # 4 (Foundation)

X-Coord	Y-Coord
0	5550.5
310	5568
390	5568
620	5557.5
900	5560

Upper Surface of Material # 5 (Bedrock)

X-Coord	Y-Coord
0	5540
900	5540

There are no explicit external forces in the data set.

GSLOPE 3.26a

LIMIT EQUILIBRIUM SLOPE STABILITY ANALYSIS

Licensed by MITRE Software Corporation, Edmonton, Canada for use at:-

Titan Environmental - Bozeman MT

Results are for Bishop's Modified Method unless otherwise noted.

File C:\STABLITY\GSLOPE\WHTMESA1.GSL   Output dated 07-03-1996 at 11:55:05

Material	Unit Wt	Cohesion	Friction Angle	Piezo Surface	Ru Value
# 1 -Earthfill	123	0	30	0	0
# 2 -Tailings	62.4	0	0	0	0
# 3 -Dike	123	0	30	0	0
# 4 -Foundation	120	0	28	0	0
# 5 -Bedrock	130	10000	45	0	0

X-centre	Y-centre	Radius	Factor of Safety	Iterations	Slices	M Alpha Warnings
322.60	5732.50	165.50	2.9103	4	11	0
22.91	5732.50	165.50	2.9101	4	11	0
323.23	5732.50	165.50	2.9164	4	12	0
322.60	5733.13	166.13	2.9101	4	11	0
322.91	5733.13	166.13	2.9159	4	12	0
323.23	5733.13	166.13	2.9164	4	12	0
322.60	5733.75	166.75	2.9099	4	11	0
322.91	5733.75	166.75	2.9160	4	12	0
323.23	5733.75	166.75	2.9164	4	12	0

Minimum Bishop Factor of Safety this run:

322.60	5733.75	166.75	2.9099	4	11	0

Material	Unit Wt pcf	C psf	Phi deg	Piezo Surf.	Ru
Earthfill	123	0	30	0	0
Tailings	62.4	0	0	0	0
Dike	123	0	30	0	0
Foundation	120	0	28	0	0
Bedrock	130	10000	45	0	0

Seismic coefficient = .1

Titan Environmental - Bozeman MT

6111.001

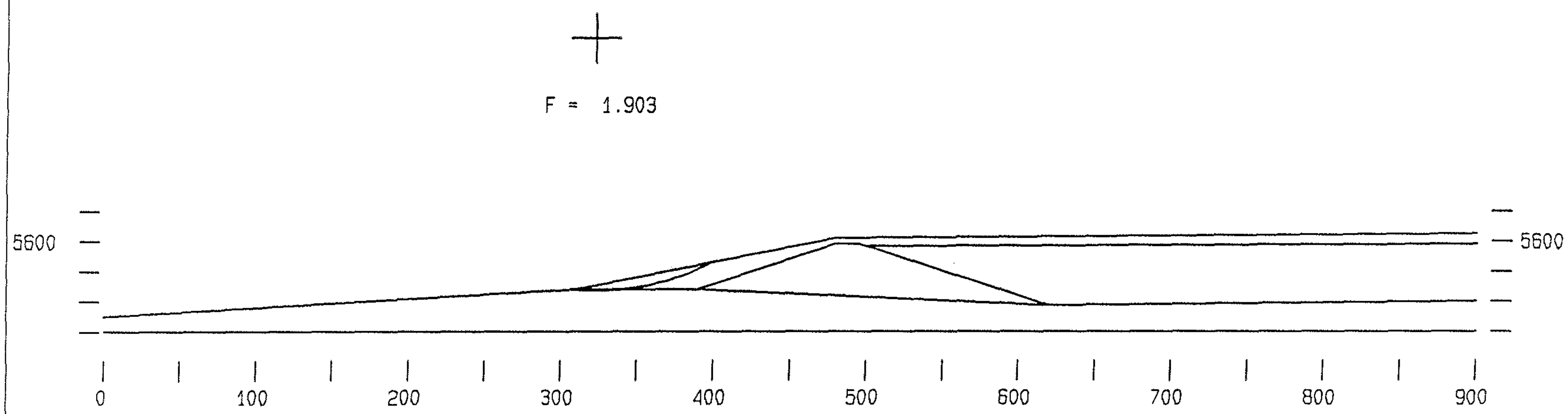
EFN White Mesa Slope Stability

7/1996

Pseudostatic Analysis

ground accln. = 0.1g

WHTMESA2.GSL



DATA FILE NAME..... C:\STABLITY\GSLOPE\WHTMESA2.GSL

[illegible] No.	6111.001
[illegible]le	EFN White Mesa Slope Stability
Date	7/1996
Label A	Pseudostatic Analysis
Label B	ground accln. = 0.1g

Max Slice Width	10
Set Neg. Normals to zero	Y
No. of Materials	5
Seismic Acceleration	.1
External Forces	0
Piezometric Surfaces	0
Unit Wt. of Pore Fluid	62.4

Material	Unit Wt	Cohesion	Friction Angle	Piezo Surface	Ru Value
# 1 -Earthfill	123	0	30	0	0
# 2 -Tailings	62.4	0	0	0	0
# 3 -Dike	123	0	30	0	0
# 4 -Foundation	120	0	28	0	0
# 5 -Bedrock	130	10000	45	0	0

Upper Surface of Material # 1 (Earthfill)

X-Coord	Y-Coord
0	5550.5
310	5568
480	5602
900	5605

Upper Surface of Material # 2 (Tailings)

X-Coord	Y-Coord
0	5550.5
310	5568
390	5568
480	5598
495	5598
500	5596.5
900	5598

Upper Surface of Material # 3 (Dike)

X-Coord	Y-Coord
[illegible]	5550.5
[illegible]	5568
390	5568
480	5598
495	5598

500	5596.5
620	5557.5
900	5560

Upper Surface of Material # 4 (Foundation)

X-Coord	Y-Coord
0	5550.5
310	5568
390	5568
620	5557.5
900	5560

Upper Surface of Material # 5 (Bedrock)

X-Coord	Y-Coord
0	5540
900	5540

There are no explicit external forces in the data set.

GSLOPE 3.26a

LIMIT EQUILIBRIUM SLOPE STABILITY ANALYSIS

Licensed by MITRE Software Corporation, Edmonton, Canada for use at:-

Titan Environmental - Bozeman MT

Results are for Bishop's Modified Method unless otherwise noted.

File C:\STABLITY\GSLOPE\WHTMESA2.GSL   Output dated 07-03-1996 at 12:14:06

Material	Unit Wt	Cohesion	Friction Angle	Piezo Surface	Ru Value
# 1 -Earthfill	123	0	30	0	0
# 2 -Tailings	62.4	0	0	0	0
# 3 -Dike	123	0	30	0	0
# 4 -Foundation	120	0	28	0	0
# 5 -Bedrock	130	10000	45	0	0

X-centre	Y-centre	Radius	Factor of Safety	Iterations	Slices	M Alpha Warnings
22.60	5732.50	165.50	1.9036	4	11	0
322.60	5732.50	166.13	1.9067	4	12	0
322.60	5732.50	164.88	1.9160	4	11	0
		MIN THIS CENTRE		1.903		
322.91	5732.50	165.50	1.9037	4	11	0
322.91	5732.50	166.13	1.9067	4	12	0
322.91	5732.50	164.88	1.9163	4	11	0
		MIN THIS CENTRE		1.903		
323.23	5732.50	165.50	1.9066	4	12	0
323.23	5732.50	166.13	1.9068	4	12	0
323.23	5732.50	164.88	1.9165	4	11	0
		MIN THIS CENTRE		1.906		
322.60	5733.13	166.13	1.9035	4	11	0
322.60	5733.13	166.75	1.9067	4	12	0
322.60	5733.13	165.50	1.9160	4	11	0
		MIN THIS CENTRE		1.903		
322.91	5733.13	166.13	1.9062	4	12	0
322.91	5733.13	166.75	1.9067	4	12	0
322.91	5733.13	165.50	1.9162	4	11	0
		MIN THIS CENTRE		1.906		

323.23	5733.13	166.13	1.9066	4	12	0
323.23	5733.13	166.75	1.9067	4	12	0
323.23	5733.13	165.50	1.9164	4	11	0
		MIN THIS CENTRE	1.906			
322.60	5733.75	166.75	1.9034	4	11	0
322.60	5733.75	167.38	1.9067	4	12	0
322.60	5733.75	166.13	1.9159	4	11	0
		MIN THIS CENTRE	1.903			
322.91	5733.75	166.75	1.9062	4	12	0
322.91	5733.75	167.38	1.9067	4	12	0
322.91	5733.75	166.13	1.9161	4	11	0
		MIN THIS CENTRE	1.906			
323.23	5733.75	166.75	1.9066	4	12	0
323.23	5733.75	167.38	1.9066	4	12	0
323.23	5733.75	166.13	1.9163	4	11	0
		MIN THIS CENTRE	1.906			

Minimum Bishop Factor of Safety this run:

322.60	5733.75	166.75	1.9034	4	11	0

PURPOSE:

Pseudostatic Slope Stability Analysis of the Side Slopes of the Cover for horizontal acceleration of 0.12g

The purpose of this calculation brief is to evaluate pseudostatic stability of the side slopes of the cover for the uranium tailings impoundments for a horizontal ground acceleration of 0.12g. The sides of the covers are sloped at 5H:1V. From the old drawings as published by UMETCO (section B-B), the side slope for Cell 4 is the tallest. Also, along the southern section of Cell 4, the ground elevation drops rapidly. Hence the side slopes of the cover located along the southern side of Cell 4 are assumed to be critical and considered for stability analysis.

METHODOLOGY:

Pseudostatic slope stability analyses have been performed for the slope geometry as shown in Figure 1. The limit equilibrium slope stability code GSLOPE, developed by MITRE Software Corporation has been used for these analyes. The Bishop's method of slices has been applied.

Geometry and Material Properties

Along the southern end of Cell 4, the topography drops at a rate of approximately 5.5% (Figure 2). The material properties as provided by Dames and Moore, 1978, have been used for these analyses. The material properties have been listed in Table 1, below.

Material No.	Type of Material	Unit weight, γ (pcf)	Cohesion, c (psf)	Angle of friction, ϕ (degrees)
1	Earthfill	123	0	30
2	Tailings	62.4	0	0
3	Dike	123	0	30
4	Foundation	120	0	28
5	Bedrock	130	10,000	45

Table 1: Material Properties

The surface of the bedrock has been determined from the bore-logs as supplied by Chen and Associates, 1978. But as this bedrock surface almost coincides with that of the foundation, assuming the bedrock layer to be about 10 ft. below the lowest point of the foundation surface, will give conservative results. Thus, for the stability analysis, the surface of competent bedrock has been assumed to be at an elevation of +5540 ft. above mean sea level (MSL).

Factor of Safety and Horizontal Acceleration required for analysis:

A factor of safety of 1.0 is acceptable for pseudostatic. Pseudostatic slope stability analysis has been performed for a maximum seismic coefficient of 0.12g as recommended by the Lawrence Livermore National Laboratory.

RESULTS:

Results for Pseudostatic case: For pseudostatic analysis, the maximum Factor of Safety calculated is 1.778 (>1.0) for a ground acceleration of 0.12g.

Hence the side slopes are stable.

REFERENCE:

a) Chen and Associates, Inc., 1978. Soil Property Study, Earth Lined Tailings Retention Cells, White Mesa Uranium Project, Blanding, Utah.

b) Dames and Moore, 1978. Site Selection and Design Study - Tailing Retention and Mill Facilities, White Mesa Uranium Project, January 17, 1978.

c) Report by "Lawrence Livermore Natioal Laboratory"

d) "GSLOPE Limit Equilibrium Slope Stability Analysis", Mitre Software Corporation, Alberta, Canada

PA 9/96

Material	Unit Wt pcf	C psf	Phi deg	Piezo Surf.	Ru
Earthfill	123	0	30	0	0
Tailings	62.4	0	0	0	0
Dike	123	0	30	0	0
Foundation	120	0	28	0	0
Bedrock	130	10000	45	0	0

Seismic coefficient = .12

Titan Environmental - Bozeman MT

6111.001

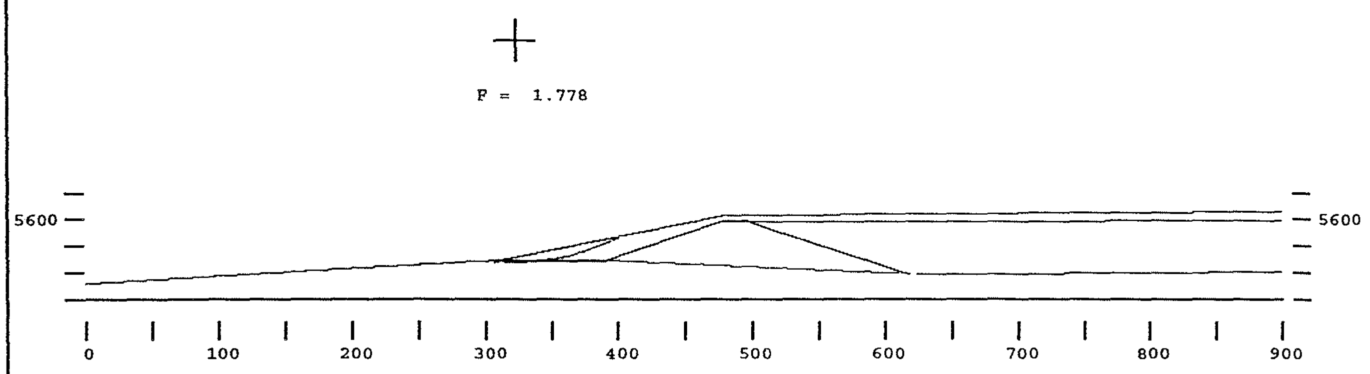
EFN White Mesa Slope Stability

7/1996

Pseudostatic Analysis

ground accln. = 0.12g

WHTMESA4.GSL



DATA FILE NAME..... C:\STABLITY\GSLOPE\...MESA4.GSL

Job No.	6111.001
Title	EFN White Mesa Slope Stability
Date	7/1996
. . A	Pseudostatic Analysis
L . B	ground accln. = 0.12g

Max Slice Width	10
Set Neg. Normals to zero	Y
No. of Materials	5
Seismic Acceleration	.12
External Forces	0
Piezometric Surfaces	0
Unit Wt. of Pore Fluid	62.4

Material	Unit Wt	Cohesion	Friction Angle	Piezo Surface	Ru Value
# 1 -Earthfill	123	0	30	0	0
# 2 -Tailings	62.4	0	0	0	0
# 3 -Dike	123	0	30	0	0
# 4 -Foundation	120	0	28	0	0
# 5 -Bedrock	130	10000	45	0	0

U Surface of Material # 1 (Earthfill)

X-Coord	Y-Coord
0	5550.5
310	5568
480	5602
900	5605

Upper Surface of Material # 2 (Tailings)

X-Coord	Y-Coord
0	5550.5
310	5568
390	5568
480	5598
495	5598
500	5596.5
900	5598

Upper Surface of Material # 3 (Dike)

X-Coord	Y-Coord
0	5550.5
310	5568
390	5568
[illegible]	5598
[illegible]	5598
500	5596.5
620	5557.5
900	5560

Upper Surface of Material # 4 (Founda[illegible]n)

X-Coord	Y-Coord
0	5550.5
310	5568
390	5568
	5557.5
	5560

Upper Surface of Material # 5 (Bedrock)

X-Coord	Y-Coord
0	5540
900	5540

There are no explicit external forces in the data set.

PTA/9/96

BA 9/96

GSLOPE 3.26a

LIMIT EQUILIBRIUM SLOPE STABILITY ANALYSIS

Licensed by MITRE Software Corporation, Edmonton, Canada for use at:-

Titan Environmental - Bozeman MT

Results are for Bishop's Modified Method unless otherwise noted.

File C:\STABLITY\GSLOPE\WHTMESA4.GSL   Output dated 08-28-1996 at 13:09:05

Material	Unit Wt	Cohesion	Friction Angle	Piezo Surface	Ru Value
# 1 -Earthfill	123	0	30	0	0
# 2 -Tailings	62.4	0	0	0	0
# 3 -Dike	123	0	30	0	0
# 4 -Foundation	120	0	28	0	0
# 5 -Bedrock	130	10000	45	0	0

X-centre	Y-centre	Radius	Factor of Safety	Iterations	Slices	M Alpha Warnings
322.60	5732.50	165.50	1.7777	4	11	0
22.91	5732.50	165.50	1.7778	4	11	0
323.23	5732.50	165.50	1.7804	4	12	0
322.60	5733.13	166.13	1.7777	4	11	0
322.91	5733.13	166.13	1.7801	4	12	0
323.23	5733.13	166.13	1.7804	4	12	0
322.60	5733.75	166.75	1.7776	4	11	0
322.91	5733.75	166.75	1.7801	4	12	0
323.23	5733.75	166.75	1.7804	4	12	0
Minimum Bishop Factor of Safety this run:						
322.60	5733.75	166.75	1.7776	4	11	0

FIGURES

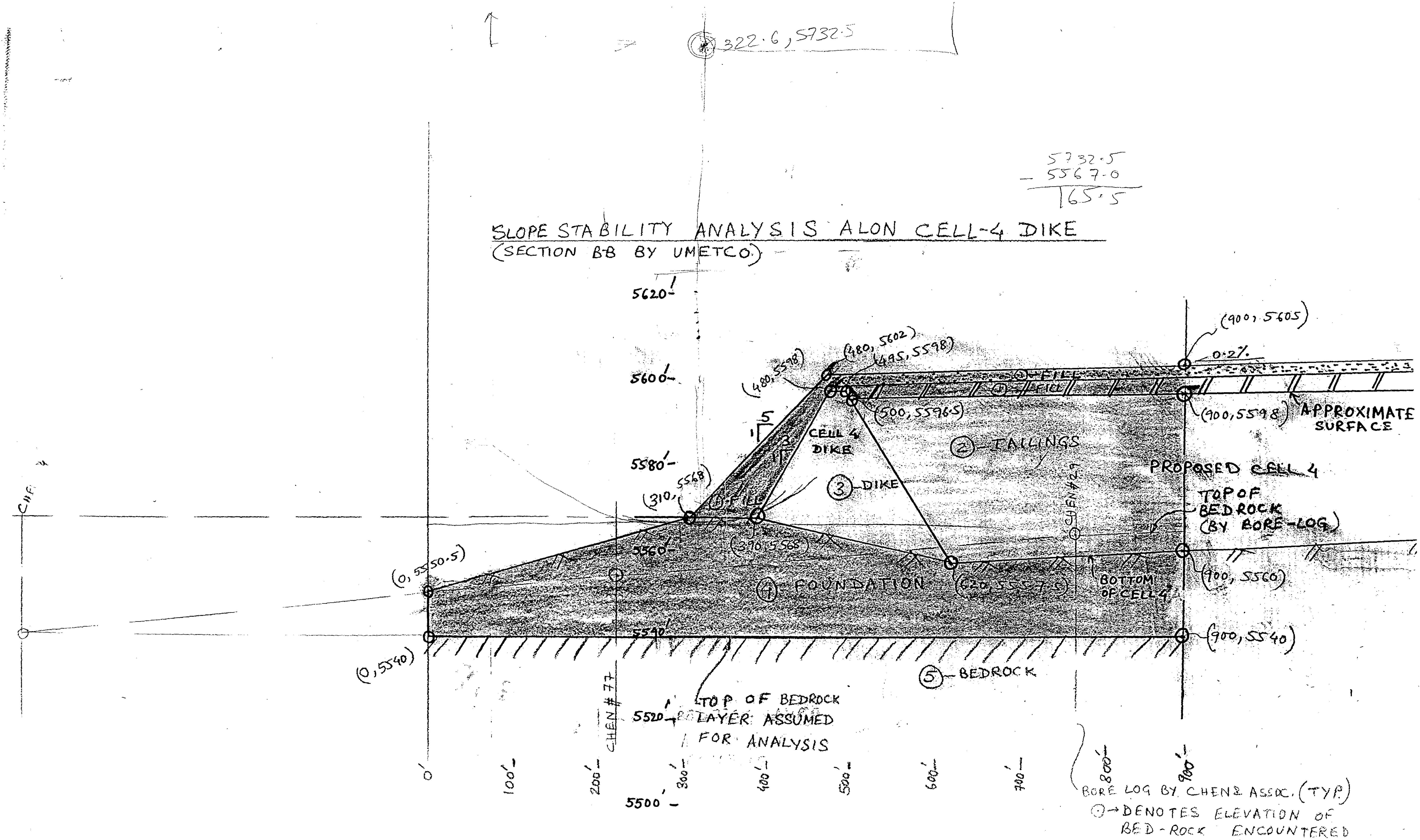
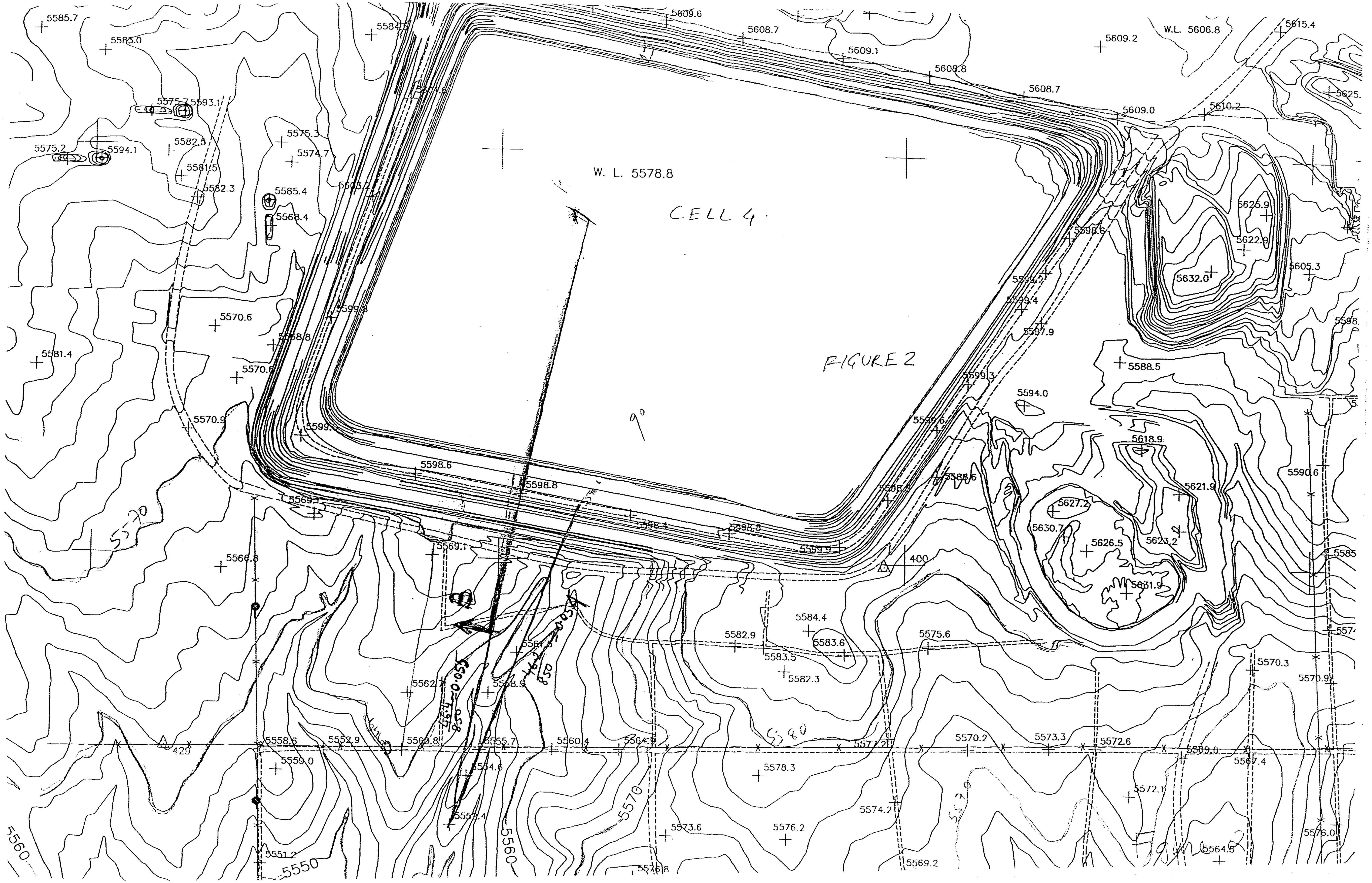


FIGURE 1

Figure 1


W. L. 5578.8
CELL 4
FIGURE 2
W.L. 5606.8
5609.6
5608.7
5609.1
5608.8
5608.7
5609.0
5610.2
5615.4
5609.2
5585.7
5583.0
5584.5
5575.2
5594.1
5582.5
5581.5
5582.3
5575.3
5574.7
5585.4
5568.4
5603.2
5570.6
5568.8
5599.8
5581.4
5570.6
5570.9
5599.0
5598.6
5598.8
5598.4
5598.8
5599.9
5569.1
5566.8
5598.6
5599.2
5599.4
5597.9
5599.3
5599.6
5588.6
5588.5
5594.0
5618.9
5621.9
5627.2
5630.7
5626.5
5623.2
5631.9
5626.9
5622.9
5632.0
5605.3
5590.6
400
5584.4
5582.9
5583.6
5583.5
5582.3
5575.6
5570.3
5570.9
5562.7
5558.5
5558.6
5552.9
5560.8
5555.7
5560.4
5564.9
5572.2
5570.2
5573.3
5572.6
5567.4
429
5559.0
5554.6
5578.3
5572.1
5574.2
5552.4
5573.6
5576.2
5576.0
5551.2
5564.5
5576.8
5569.2
5560
5550
5570
5580
5570
5560

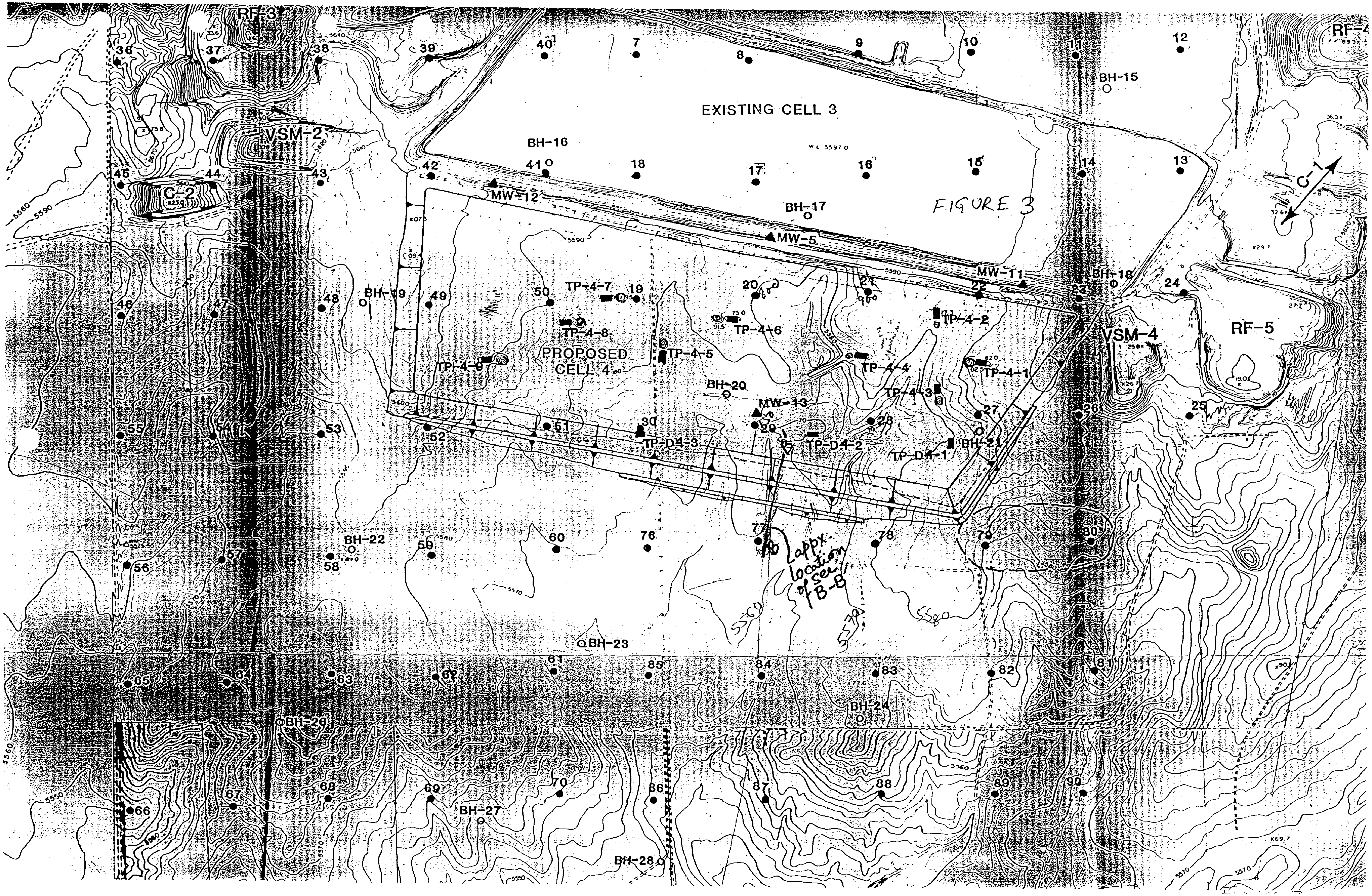


FIGURE 3
EXISTING CELL 3
PROPOSED CELL 4
RF-3
RF-4
RF-5
VSM-2
VSM-4
C-1
C-2
BH-15
BH-16
BH-17
BH-18
BH-19
BH-20
BH-21
BH-22
BH-23
BH-24
BH-26
BH-27
BH-28
MW-5
MW-11
MW-12
MW-13
TP-4-1
TP-4-2
TP-4-3
TP-4-4
TP-4-5
TP-4-6
TP-4-7
TP-4-8
TP-4-9
TP-D4-1
TP-D4-2
TP-D4-3
appx. location of sec. B-B
5560
5570
5580
5590
5600

APPENDIX

chen and associates, inc.
CONSULTING ENGINEERS

SOIL & FOUNDATION ENGINEERING
96 S. ZUNI • DENVER, COLORADO 80223 • 303/744-7105
1924 EAST FIRST STREET • CASPER, WYOMING 82601 • 307/234-2126

SECTION 2

Extracted Data From

SOIL PROPERTY STUDY
EARTH LINED TAILINGS RETENTION CELLS
WHITE MESA URANIUM PROJECT
BLANDING, UTAH

Prepared for:

ENERGY FUELS NUCLEAR, INC.

PARK CENTRAL
1515 ARAPAHOE STREET
DENVER, COLORADO 80202

Job No. 16,406

July 18, 1978

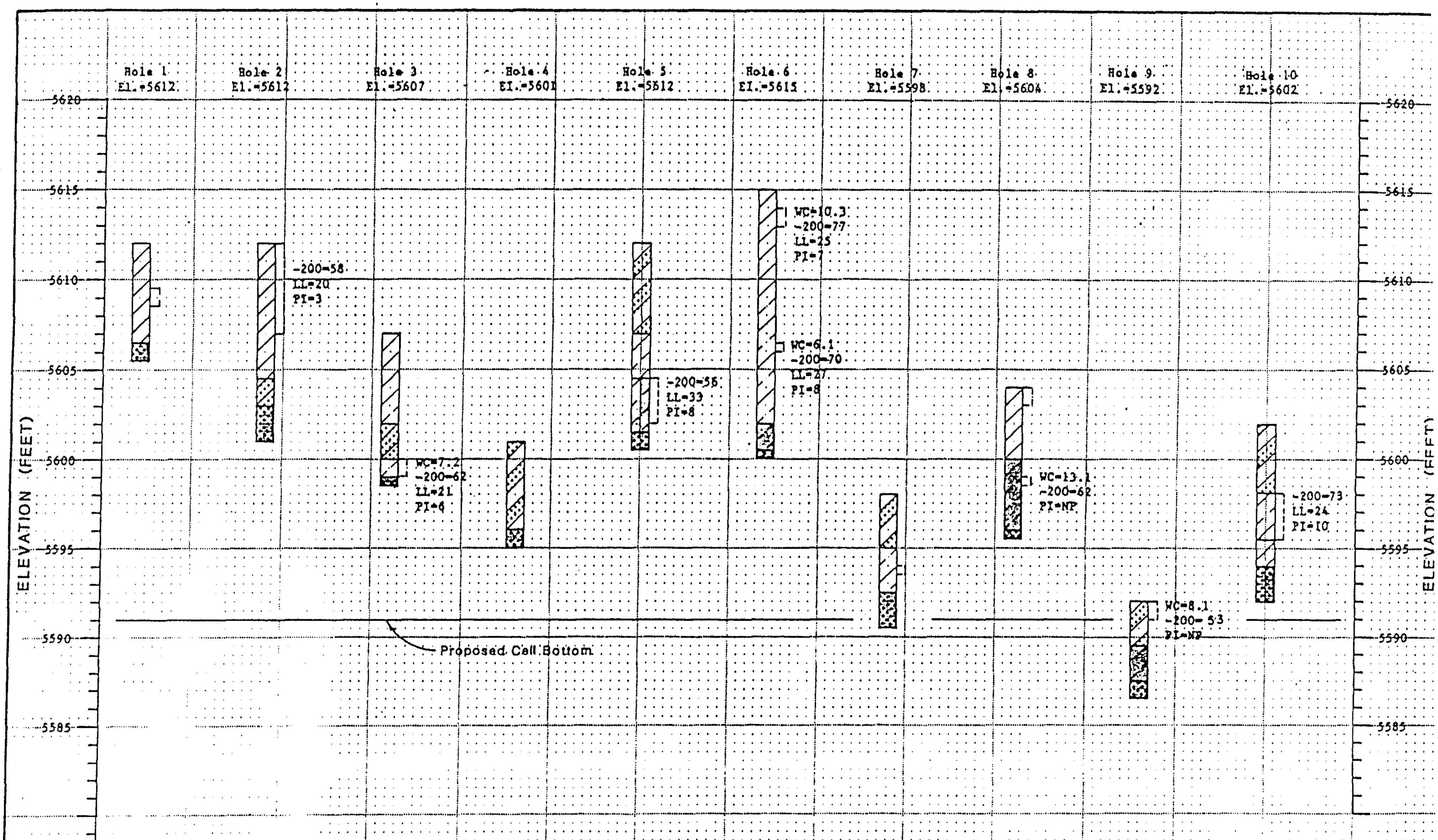


FIGURE 2
LOGS OF EXPLORATORY BORINGS
(CHEN & ASSOCIATES)
WHITE MESA PROJECT

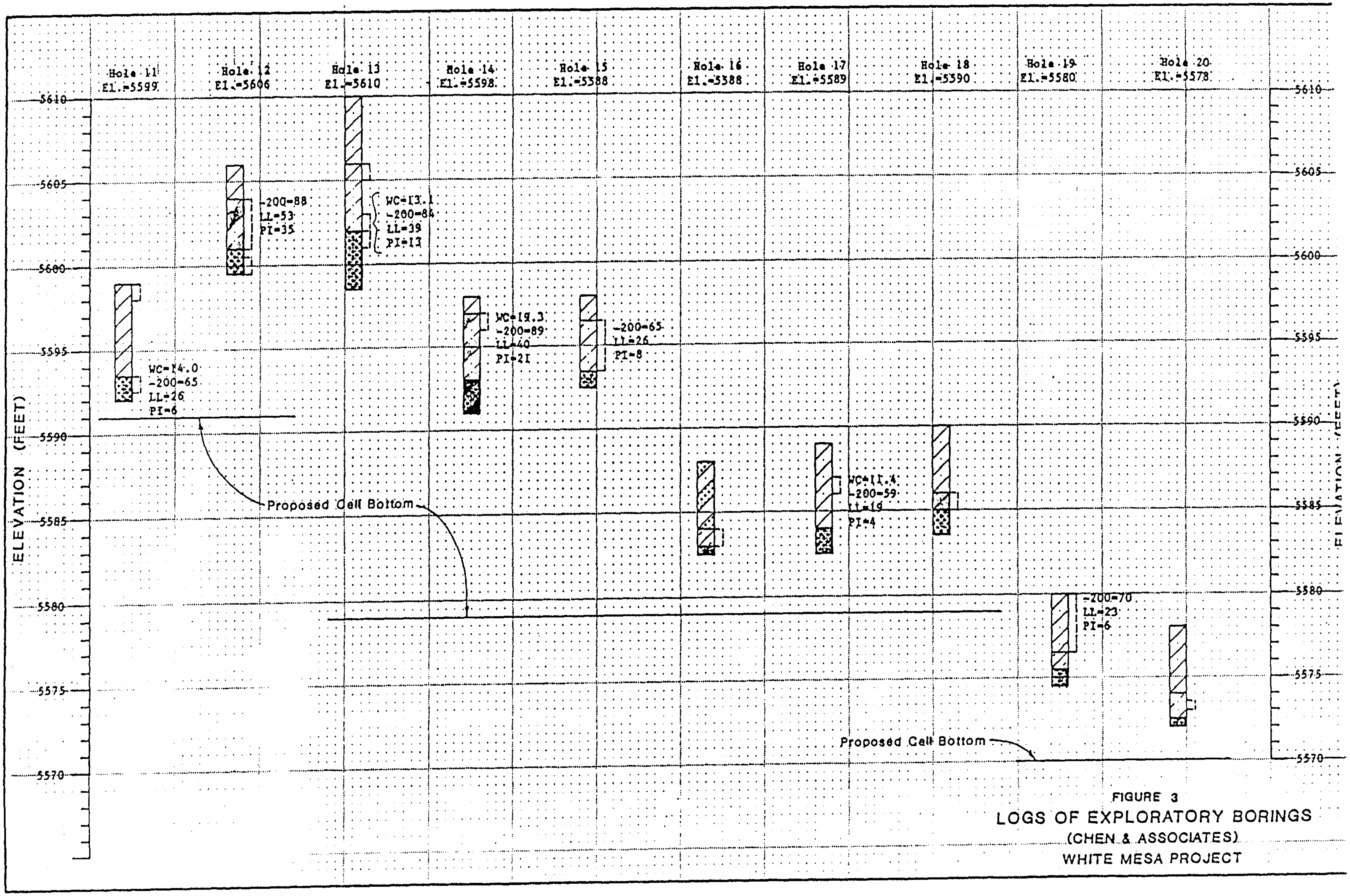


FIGURE 3
LOGS OF EXPLORATORY BORINGS
(CHEN & ASSOCIATES)
WHITE MESA PROJECT

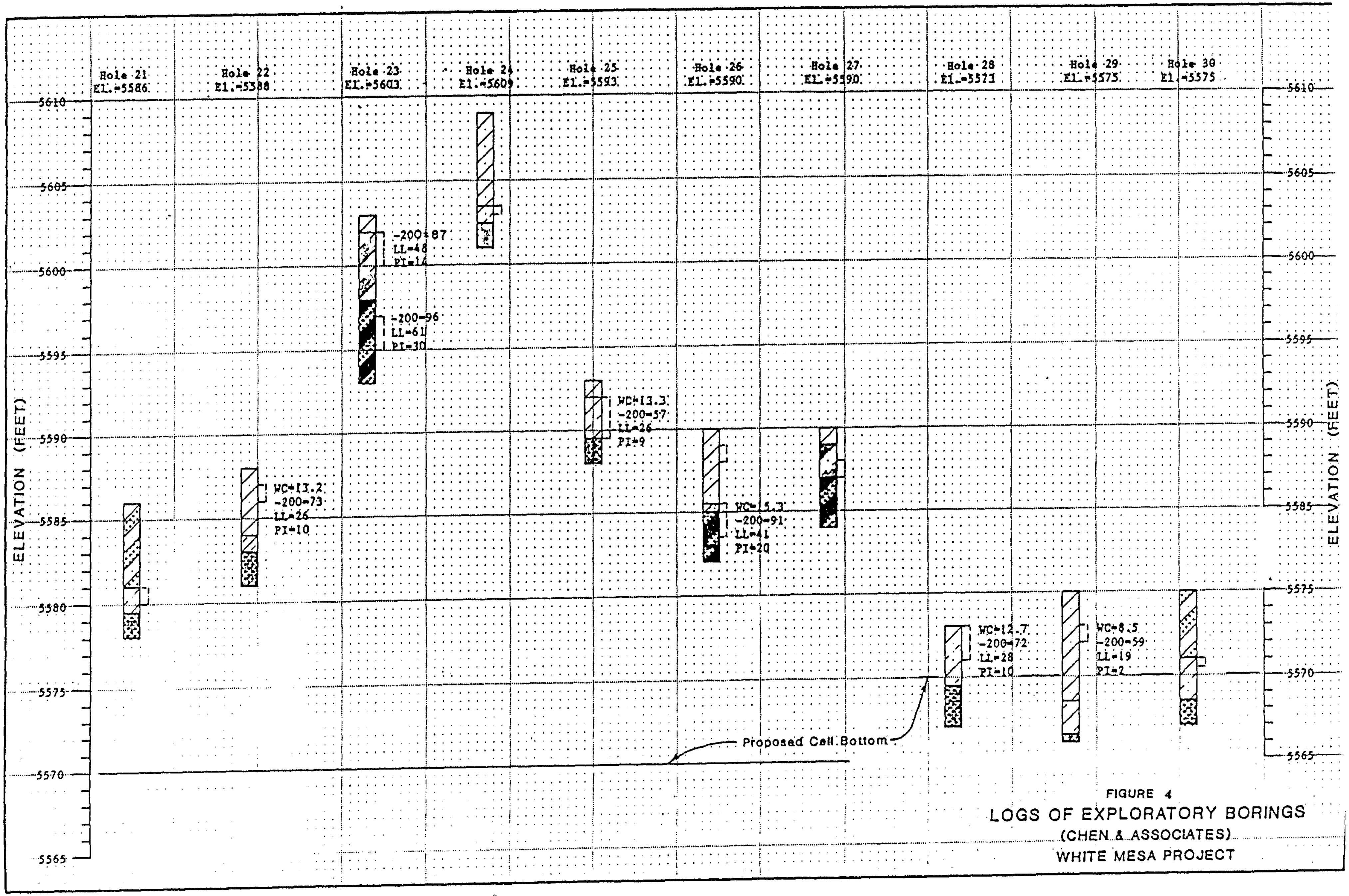


FIGURE 4
LOGS OF EXPLORATORY BORINGS
(CHEN & ASSOCIATES)
WHITE MESA PROJECT

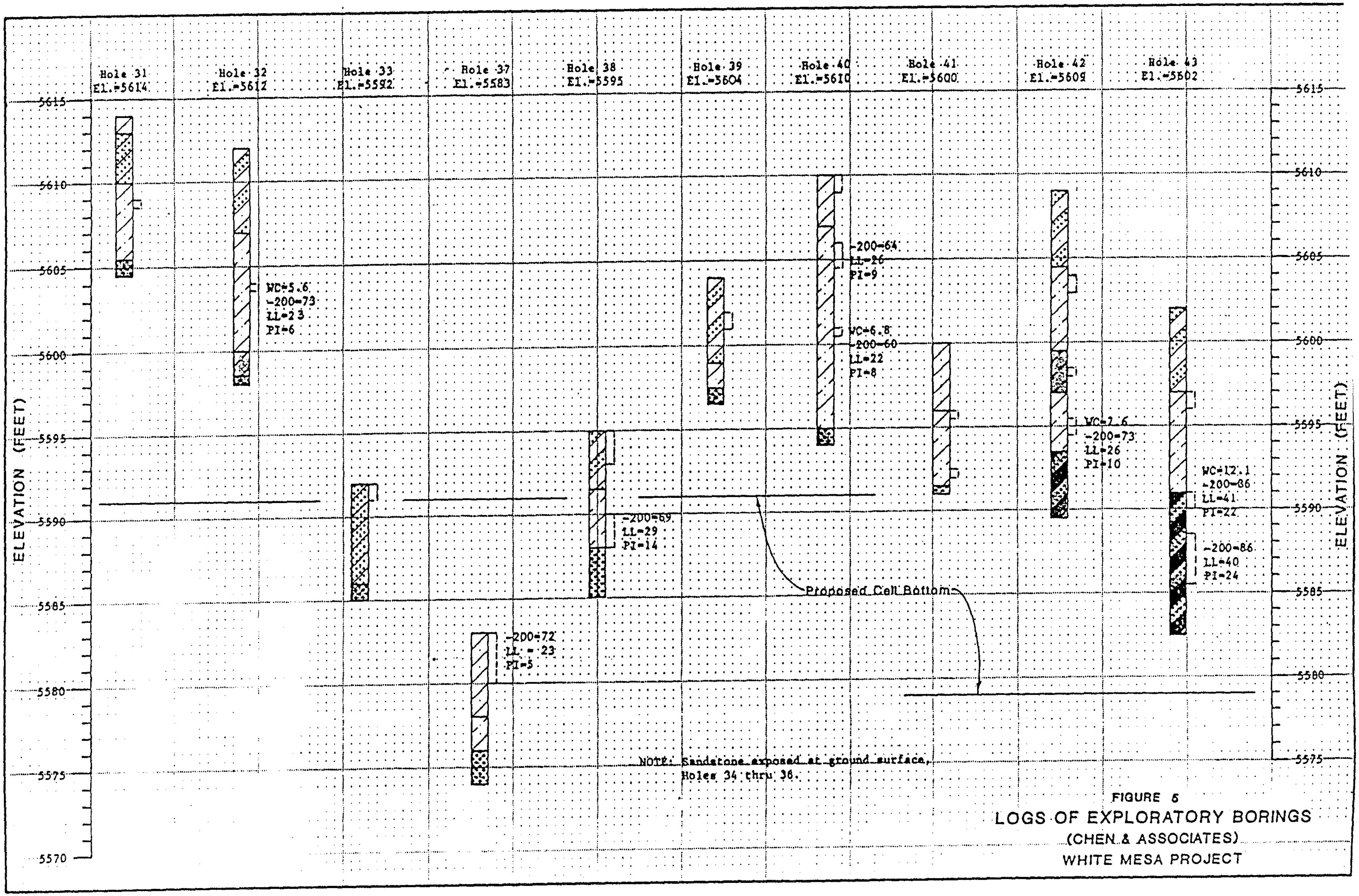


FIGURE 5

LOGS OF EXPLORATORY BORINGS

(CHEN & ASSOCIATES)

WHITE MESA PROJECT

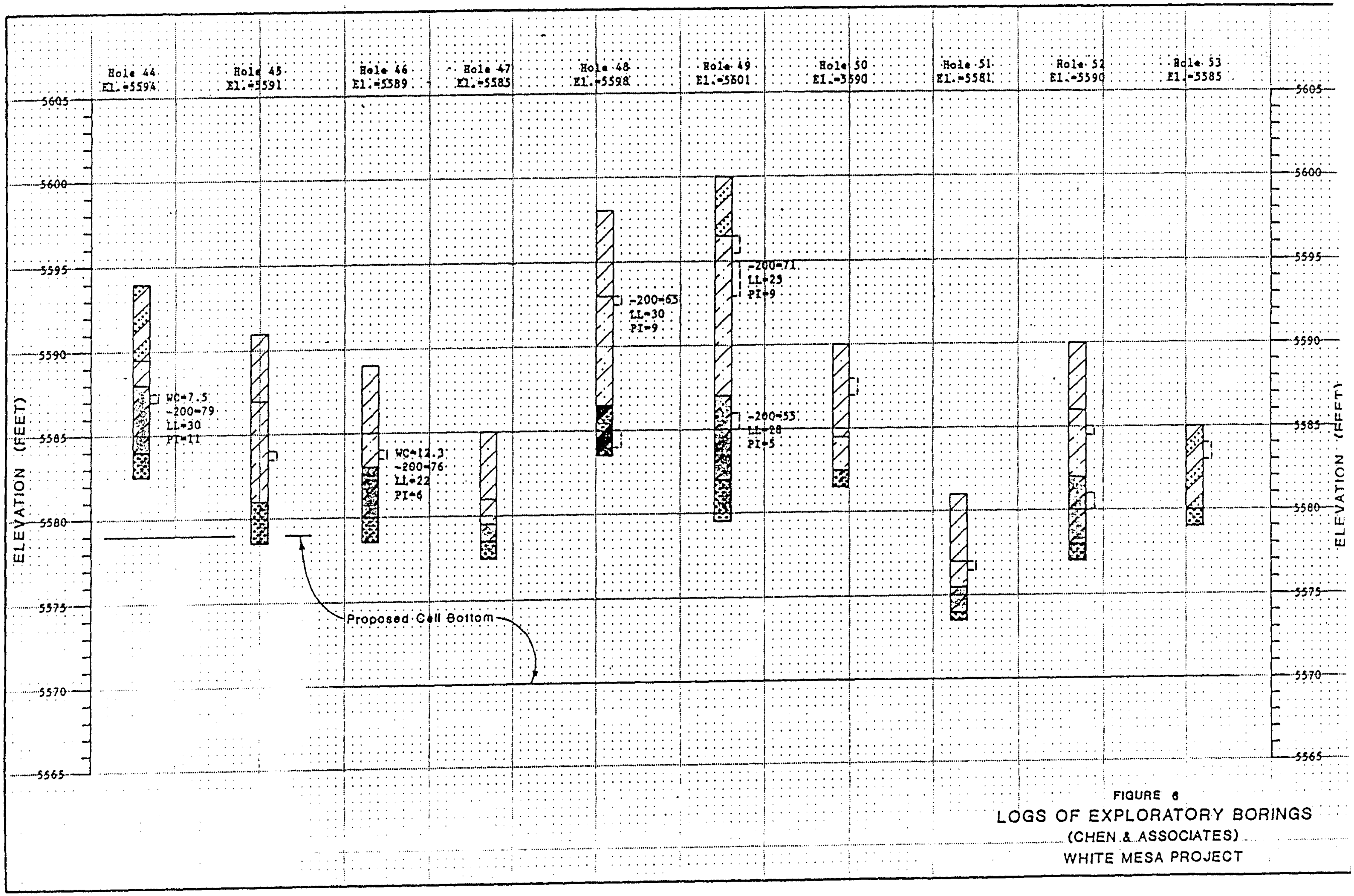


FIGURE 6
LOGS OF EXPLORATORY BORINGS
(CHEN & ASSOCIATES)
WHITE MESA PROJECT

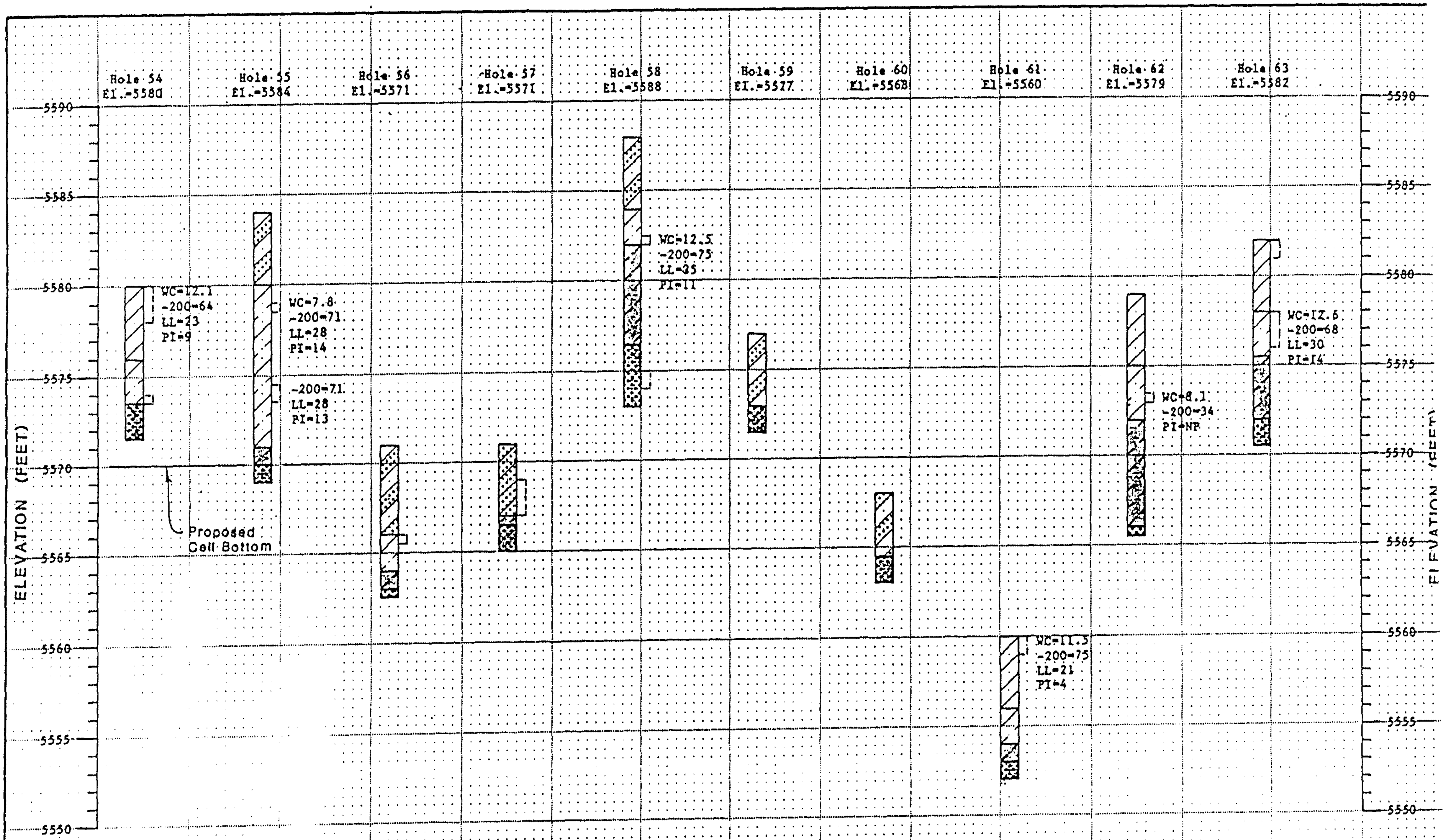


FIGURE 7

LOGS OF EXPLORATORY BORINGS

(CHEN & ASSOCIATES)

WHITE MESA PROJECT

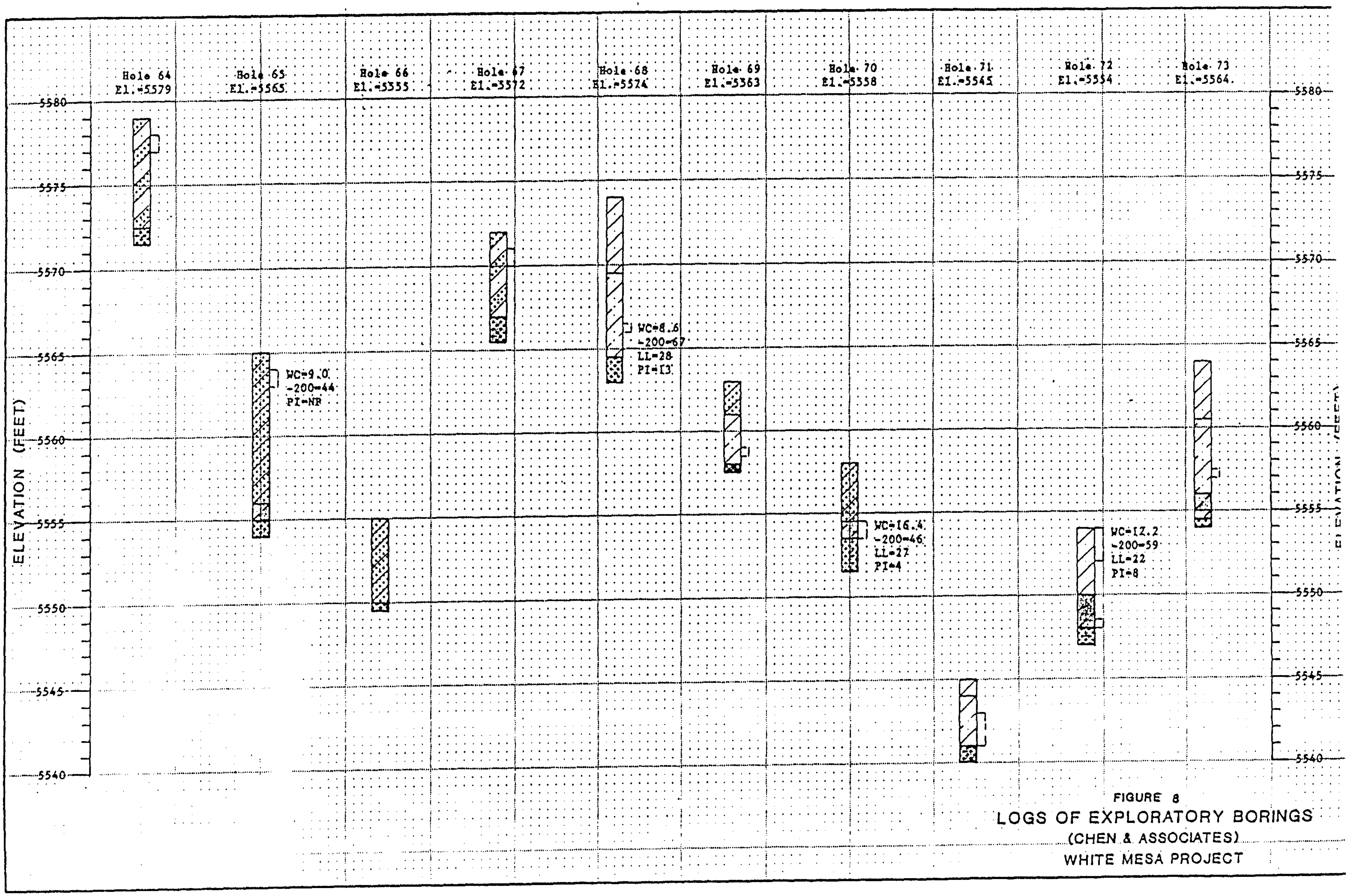
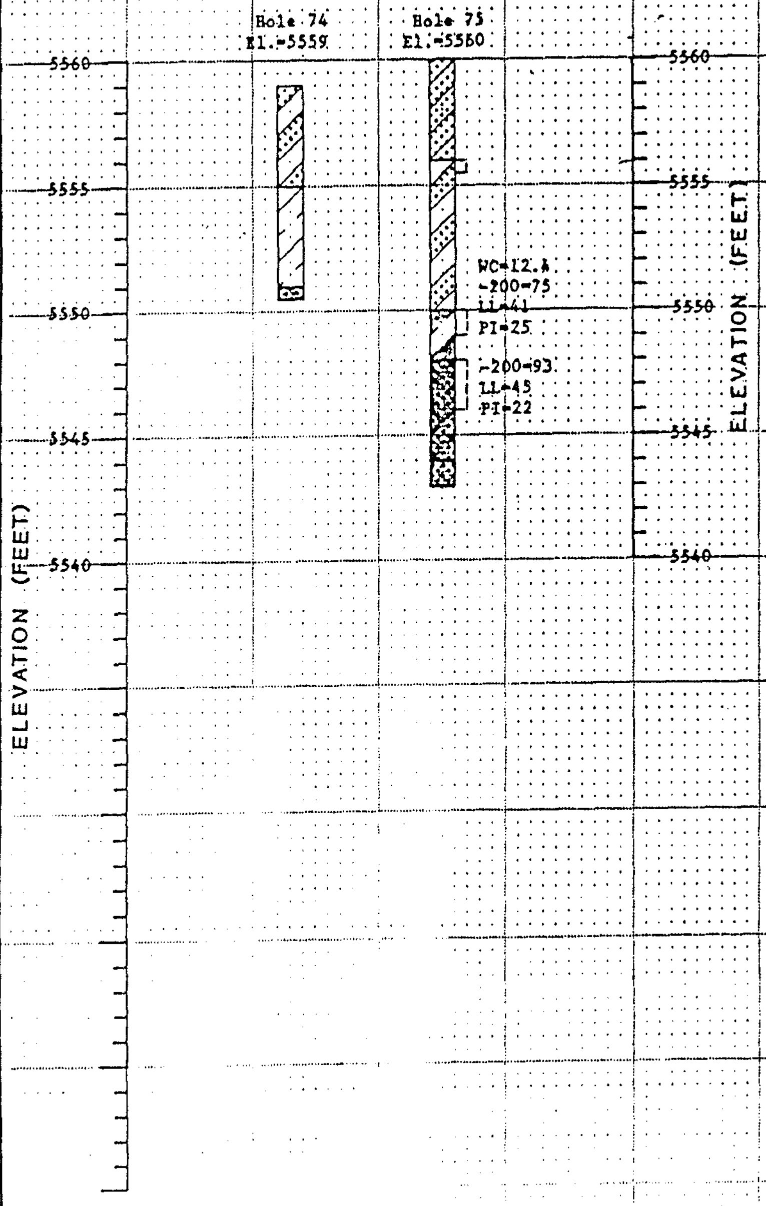


FIGURE 8
LOGS OF EXPLORATORY BORINGS
(CHEN & ASSOCIATES)
WHITE MESA PROJECT



Legend:

- Sand (SM), silty, fine to medium grained, approximately 40-50% silt, slightly moist to moist, reddish brown.
- Sand, silty to sandy silt (SM-ML), fine to medium grained, approximately 50-60% silt, slightly moist to moist, reddish brown.
- Silt (ML), sandy, approximately 60-70% silt, fine to medium sand size, slightly calcareous with depth, slightly moist to moist, reddish brown to light brown.
- Clay, silty to sandy silt (CL-ML), approximately 60-75% low to non-plastic fines, fine to medium sand size, slightly to moderately calcareous with depth, slightly moist, light brown.
- Clay (CL), highly calcareous, sandy to silty, approximately 50-75% low plasticity fines, scattered very hard lenses/layer, dry to slightly moist, light tan to white.
- Weathered claystone (CL-CH), approximately 90% medium to high plasticity fines, moist, gray-brown.
- Claystone, bedrock, slightly moist, greenish gray.
- Claystone-sandstone bedrock, lightly cemented, roughly stratified, fine to medium grained, greenish gray.
- Sandstone bedrock, well cemented with depth, fine to medium grained, tan to gray.
- Disturbed auger sample.

NOTES:

(1) Test holes were drilling on May 17 and 18, 1978 with a 12-inch, single-flight, power auger.
(2) Elevations are approximate and taken from contours shown on Fig. 1.
(3) No free water was found in test holes at the time of drilling.
(4) WC = Water Content (%);
-200 = Percent Passing No. 200 Sieve;
LL = Liquid Limit (%);
PI = Plasticity Index (%)
NP = Non-Plastic.

FIGURE 9

LOGS OF EXPLORATORY BORINGS

(CHEN & ASSOCIATES)

WHITE MESA PROJECT

SECTION 4

Extracted Data From

REPORT
SITE SELECTION AND DESIGN STUDY
TAILING RETENTION AND MILL FACILITIES
WHITE MESA URANIUM PROJECT
BLANDING, UTAH
FOR ENERGY FUELS NUCLEAR, INC.

Dames and Moore

January 17, 1978

09973-015-14

3.8 Stability

3.8.1 Slope Stability

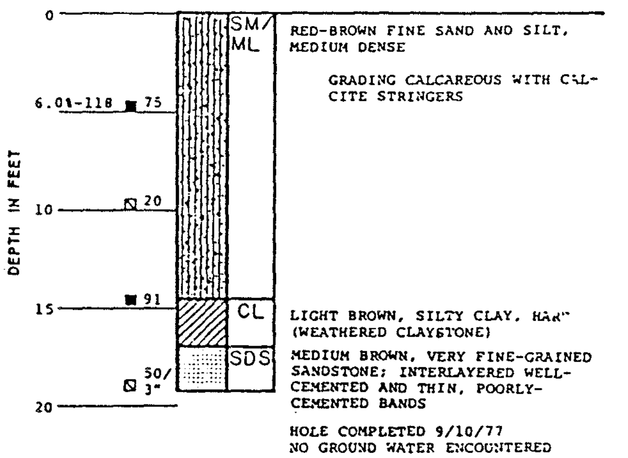
The external dikes formed by cover placement on Cell 2 will be extended to a reclaimed slope of 5(H) to 1(V) but may exist on an interim basis as 3(H) to 1(V) slopes until final reclamation. A stability analysis was performed using the 3(H) to 1(V) slopes. The maximum section of the dike will have a 15-foot wide berm at its base. The soil strength parameters used in the analysis are those developed by Dames & Moore (1978a) and are as follows:

Soil Parameters
for
Slope Stability Analysis

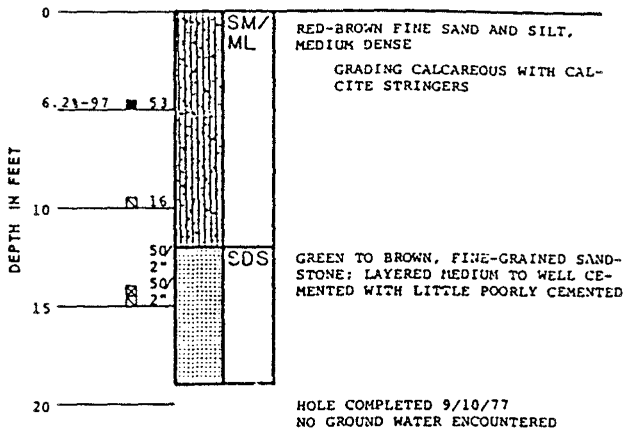
Section	Density (Pcf)	(Degrees)	C (psf)
Embankment	123	30	0
Tailings	62.4	0	0
Foundation Soils	120	28	0
Bedrock	130	45	10,000

From UMETCO, 1988

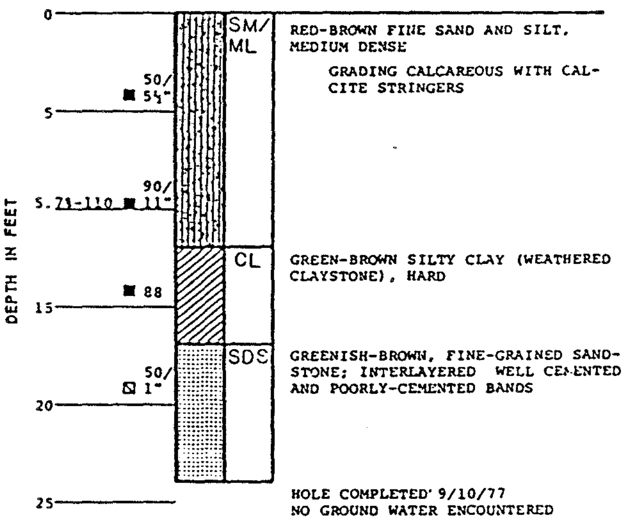
BORING NO. 1
EL. 5629.0 FT.



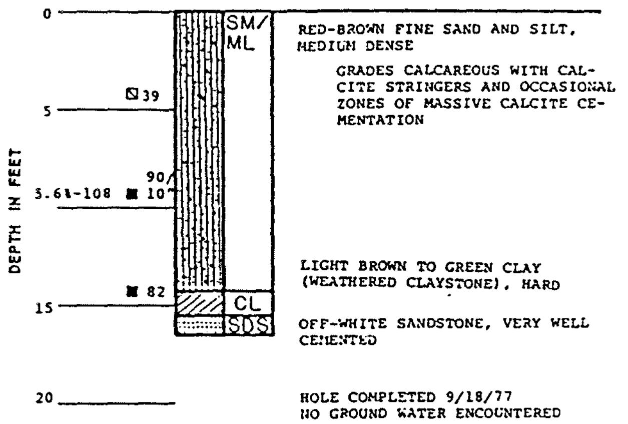
BORING NO. 5
EL. 5632.9 FT.



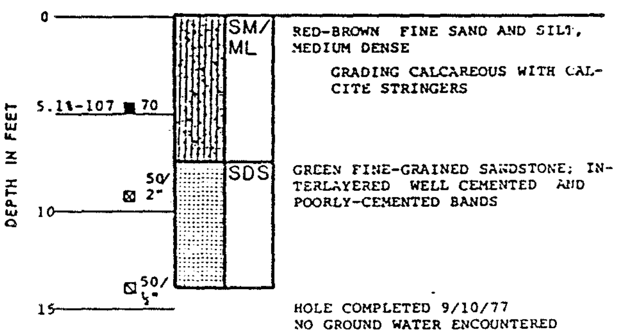
BORING NO. 2
EL. 5634.3 FT.



BORING NO. 6
EL. 5633.5 FT.



BORING NO. 4
EL. 5623.2 FT.



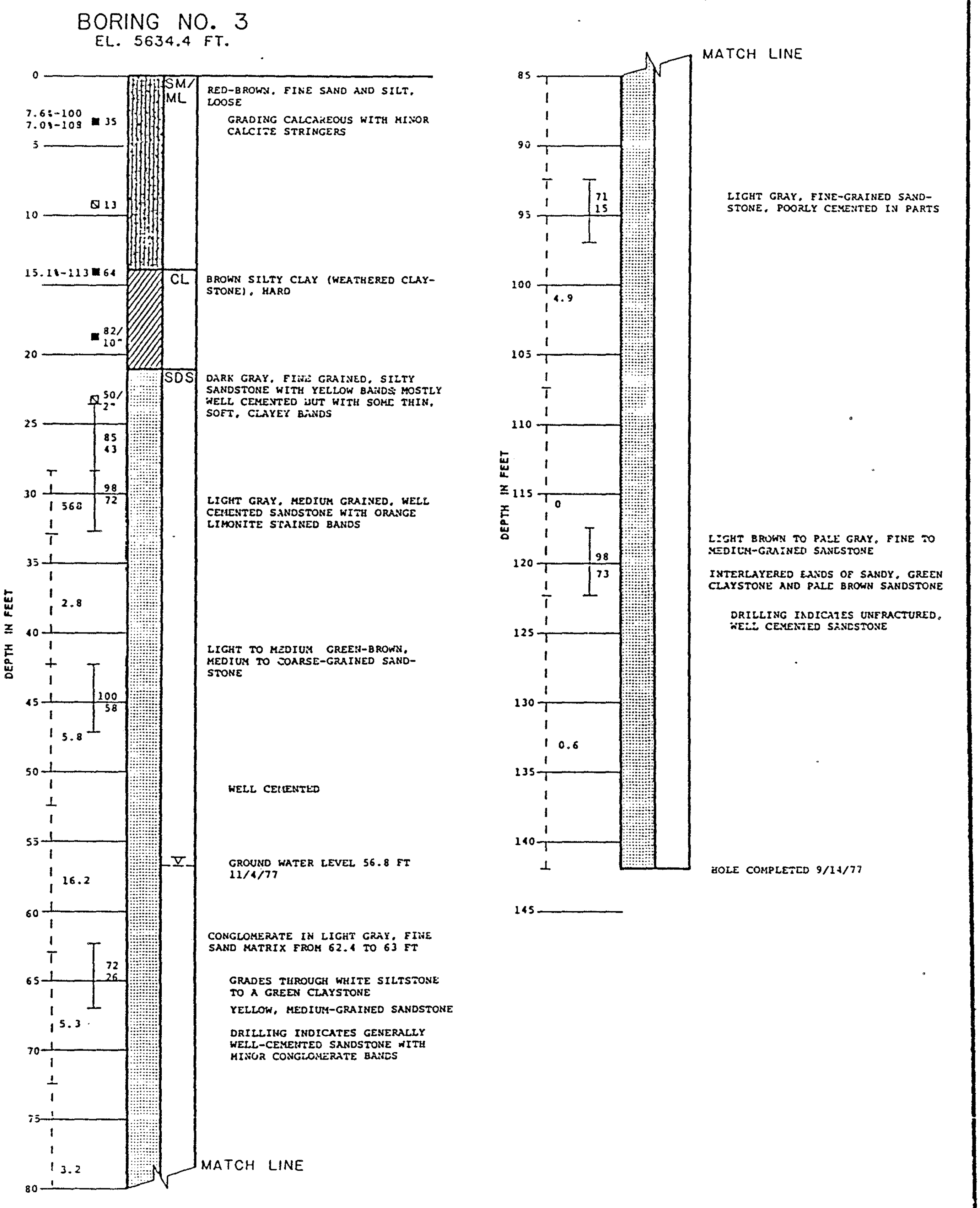
KEY

A-B ■ C	INDICATES DEPTH AT WHICH UNDISTURBED SAMPLE WAS EXTRACTED USING DAMES & MOORE SAMPLER
⊠ C	INDICATES DEPTH AT WHICH DISTURBED SAMPLE WAS EXTRACTED USING DAMES & MOORE SAMPLER
□ C	INDICATES SAMPLE ATTEMPT WITH NO RECOVERY
⧅ C	INDICATES DEPTH AT WHICH DISTURBED SAMPLE WAS EXTRACTED USING STANDARD PENETRATION TEST SAMPLER
A	FIELD MOISTURE EXPRESSED AS A PERCENTAGE OF THE DRY WEIGHT OF SOIL
B	DRY DENSITY EXPRESSED IN LBS/CU FT
C	BLOWS/FT OF PENETRATION USING A 140-LB HAMMER DROPPING 30 INCHES
[D E	INDICATES NC CORE RUN
D	PERCENT OF CORE RECOVERY
E	RQD*
I F	INDICATES PACKER TEST SECTION
F	PERMEABILITY MEASURED BY SINGLE PACKER TEST IN FT/YR
NA	NOT APPLICABLE (USED FOR RQD IN CLAYS OR MECHANICALLY FRACTURED ZONES)
NOTE:	ELEVATIONS PROVIDED BY ENERGY FUELS NUCLEAR, INC.

* ROCK QUALITY DESIGNATION -- PERCENTAGE OF CORE RECOVERED IN LENGTHS GREATER THAN 4 INCHES

LOG OF BORINGS

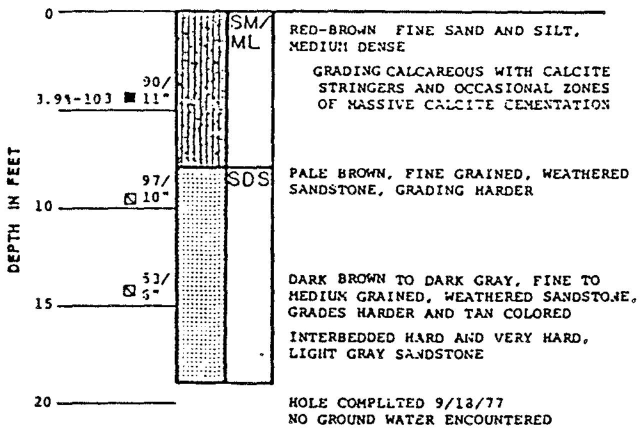
DAMES & MOORE



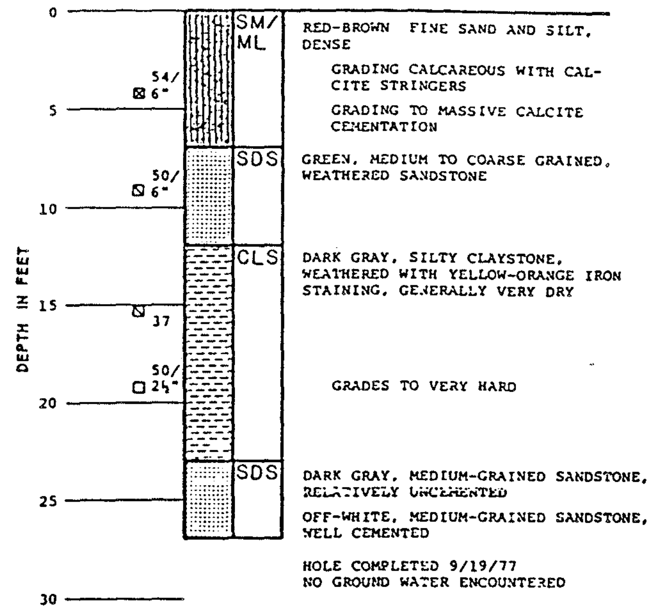
LOG OF BORINGS

DAMES & MOORE

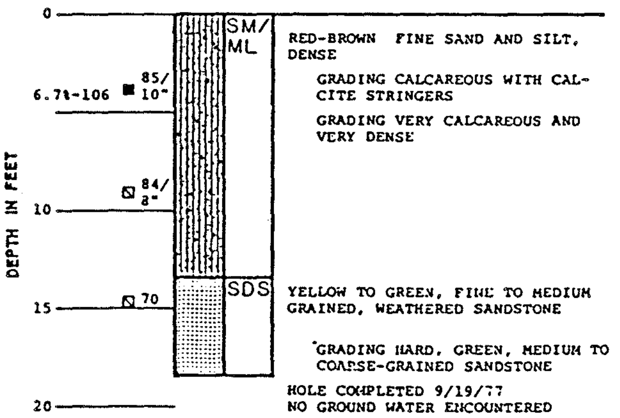
BORING NO. 7
EL. 5656.9 FT.



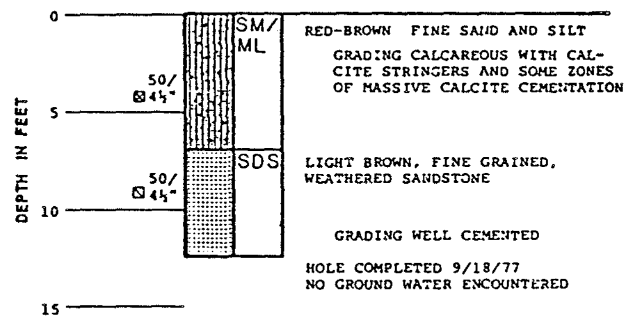
BORING NO. 8
EL. 5668.4 FT.



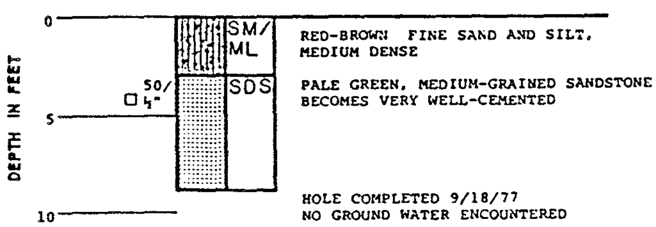
BORING NO. 10
EL. 5690.9 FT.



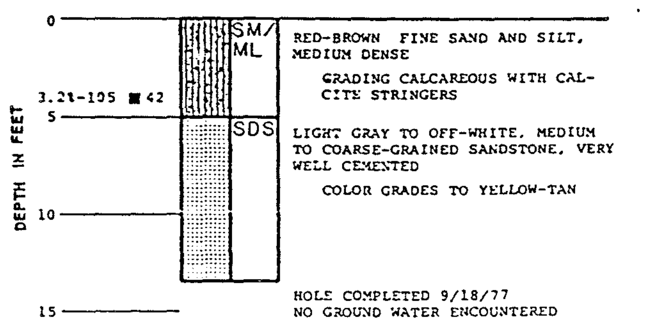
BORING NO. 11
EL. 5677.8 FT.



BORING NO. 13
EL. 5602.4 FT.

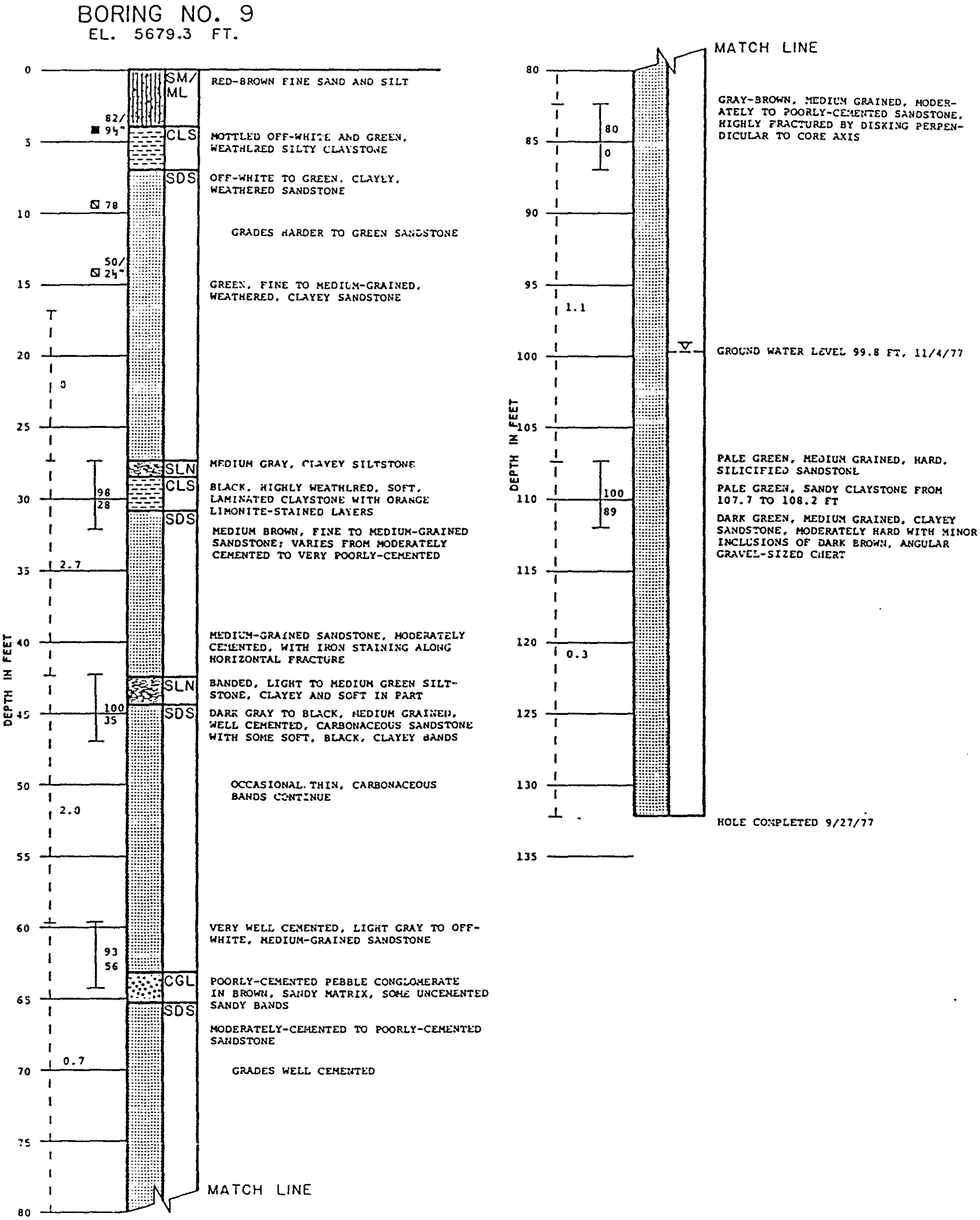


BORING NO. 14
EL. 5597.5 FT.



LOG OF BORINGS

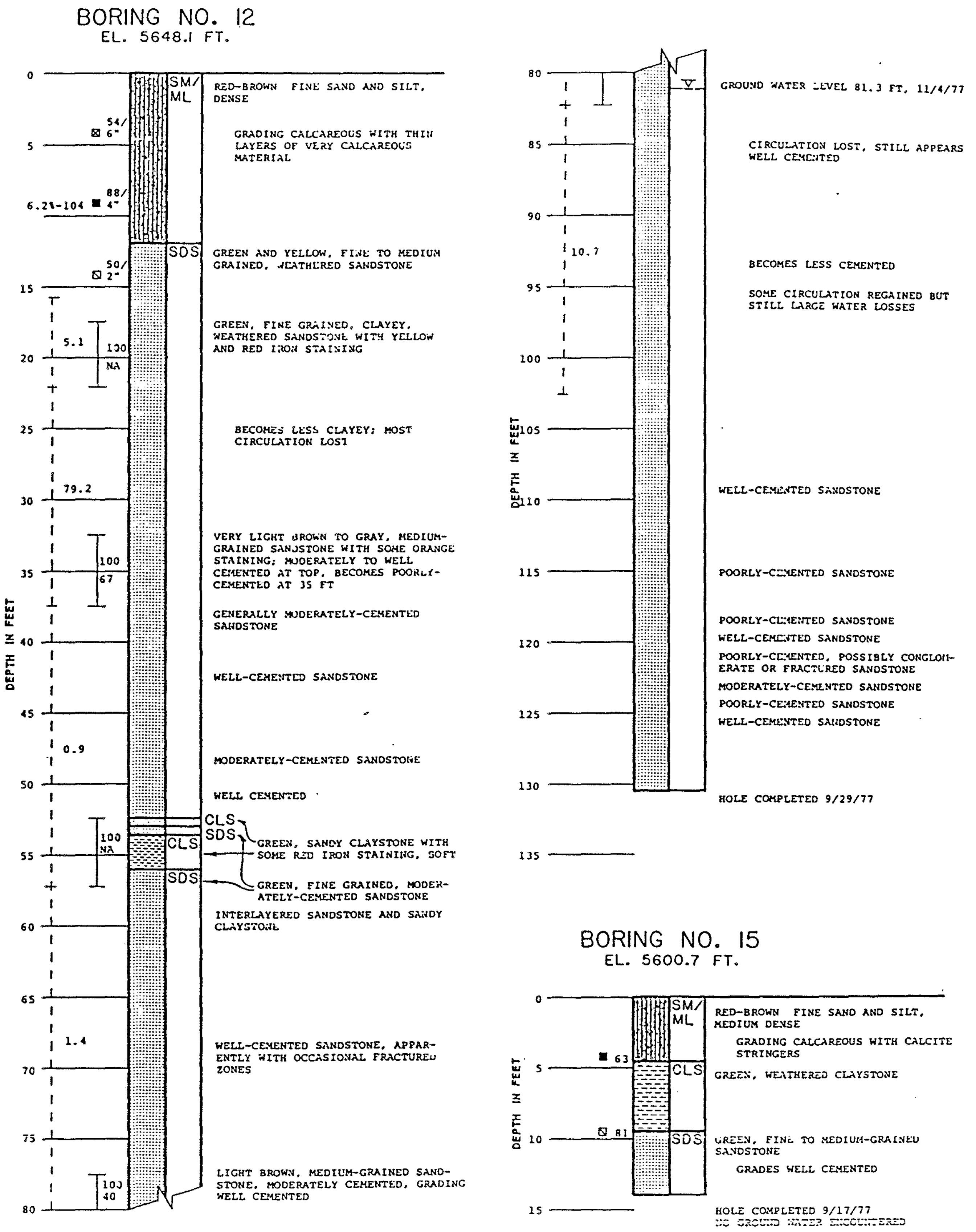
DAMES & MOORE



LOG OF BORINGS

DAMES & MOORE

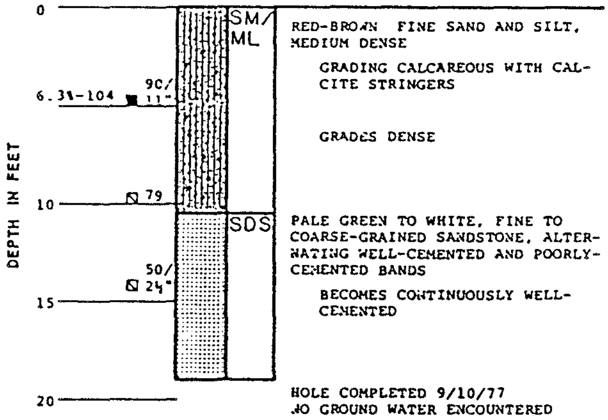
PLATE A-6



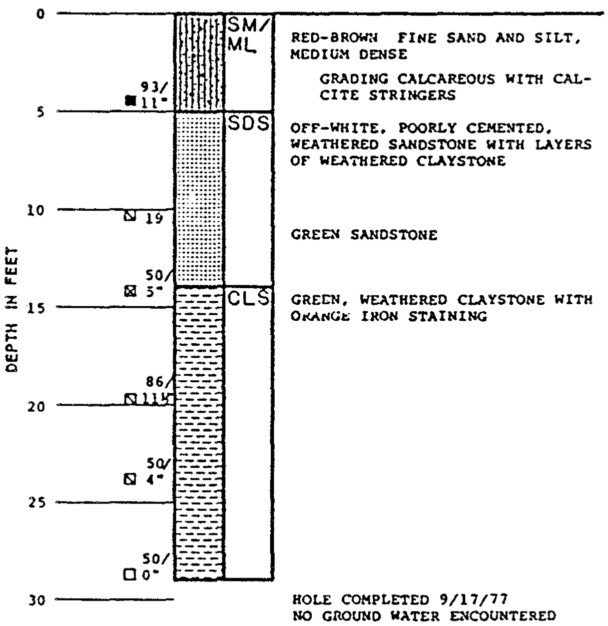
LOG OF BORINGS

DAMES & MOORE

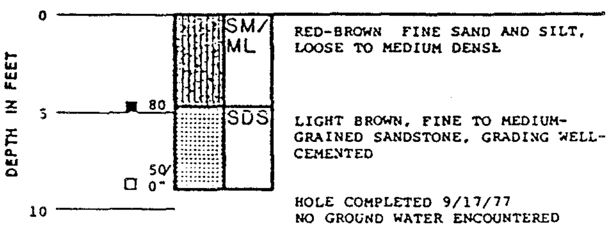
BORING NO. 16
EL. 5597.5 FT.



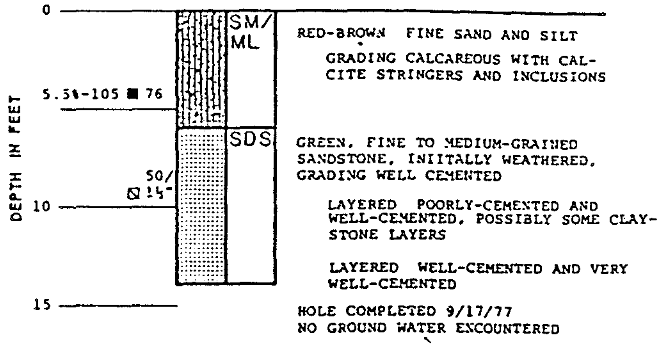
BORING NO. 18
EL. 5608.5 FT.



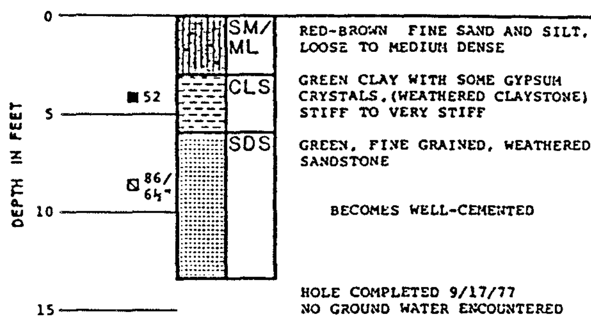
BORING NO. 20
EL. 5570.4 FT.



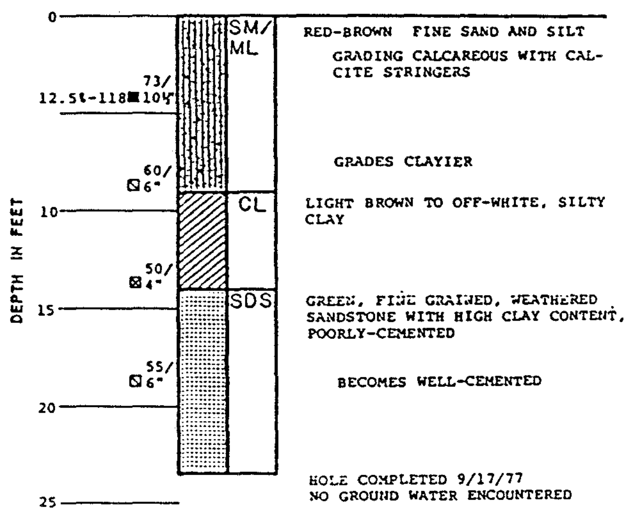
BORING NO. 17
EL. 5582.0 FT.



BORING NO. 21
EL. 5584.5 FT.



BORING NO. 22
EL. 5585.3 FT.



LOG OF BORINGS

DAMES & MOORE

BORING NO. 19
EL. 5600.3 FT.

DEPTH IN FEET

0 — SM/ML — RED-BROWN FINE SAND AND SILT, MEDIUM DENSE

GRADING CALCAREOUS WTIH CALCITE STRINGERS

93/11" — 12.4↑-92

GRADES VERY CALCAREOUS AND VERY DENSE

BECOMES VERY LOOSE, POSSIBLY WITH VOIDS

10 — 10

BECOMES DENSE

95/9"

15

SDS — GREEN, FINE TO MEDIUM-GRAINED SANDSTONE, WEATHERED, WITH SOME ORANGE AND YELLOW IRON STAINING

85/9½"

20

50/4½"

GRAY-GREEN, FINE TO MEDIUM GRAINED, WEATHERED, CLAYEY SANDSTONE WITH ORANGE AND YELLOW IRON STAINING

25 — 98 / 71

BECOMES LESS WEATHERED WITH LESS CLAY, PREDOMINANTLY GRAY WITH ORANGE IRON STAINING, MODERATELY CEMENTED, MEDIUM GRAINED

30

7.0

35

BROWN-YELLOW, COARSE-GRAINED SANDSTONE

CGL — FINE GRAVEL CONGLOMERATE WITH CONSIDERABLE COARSE-GRAINED SAND AND CALCAREOUS MATRIX

SDS — 85 / 8

40

BROWN TO YELLOW, COARSE-GRAINED SANDSTONE WITH CONSIDERABLE NEAR HORIZONTAL FRACTURING AND SOME ORANGE IRON STAINING, MODERATELY CEMENTED

943

45

50

WATER RETURN COMPLETELY LOST

LIGHT GRAY, MEDIUM TO COARSE-GRAINED SANDSTONE; HIGHLY FRACTURED ALONG HORIZONTAL BEDDING, CONSIDERABLE LIMONITE STAINING ALONG BEDDING FRACTURES; MODERATELY CEMENTED TO UNCEMENTED, CORE LOSSES ASSUMED DUE TO WASHING AWAY OF UNCEMENTED ZONES

55 — 78 / 0

60

LIMITED WATER RETURN

65

BECOMES VERY UNCEMENTED, WATER RETURN LOST

70

HOLE LOST AT 72 FT; HOLE 19A DRILLED 15 FT SOUTH OF HOLE 19; NO WATER RETURN OBTAINED; NO SAMPLING POSSIBLE; HOLE LOGGED FROM DRILLING PROGRESS

75

VERY WELL-CEMENTED SANDSTONE (72 FT)
MODERATELY-CEMENTED SANDSTONE (73 FT)

80

MODERATELY WELL-CEMENTED CONGLOMERATE OR FRACTURED SANDSTONE GRADING BETTER CEMENTED

85

GRADING LESS CEMENTED

VERY POORLY-CEMENTED SANDSTONE

MODERATELY-CEMENTED CLAYSTONE

90

POORLY-CEMENTED SANDSTONE WITH MINOR HARD LENSES

MODERATELY-CEMENTED SANDSTONE

GRADES LESS CEMENTED

95

APPEARS CLAYEY

MODERATELY-CEMENTED SANDSTONE

100

105

110 — GROUND WATER LEVEL 110 FT, 11/4/77

POORLY-CEMENTED SANDSTONE WITH OCCASIONAL BANDS OF GRAVEL OR CONGLOMERATE

115

VERY WELL-CEMENTED SANDSTONE

VERY POORLY-CEMENTED SANDSTONE

VERY WELL-CEMENTED SANDSTONE

120

125

BECOMES LESS CEMENTED AND CLAYEY

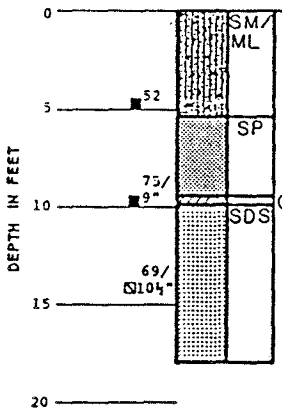
HOLE COMPLETED 9/25/77

130

LOG OF BORINGS

DAMES & MOORE

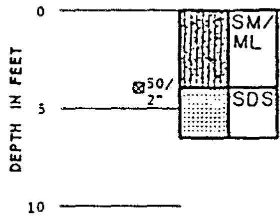
BORING NO. 23
EL. 5555.9 FT.



RED-BROWN FINE SAND AND SILT, LOOSE TO MEDIUM DENSE
GRADING CALCAREOUS WITH CALCITE STRINGERS
GRADES MEDIUM-GRAINED
MOTTLED COLORS FROM RED TO WHITE AND YELLOW
YELLOW TO LIGHT BROWN, MEDIUM TO COARSE-GRAINED SAND (WEATHERED SANDSTONE)
GREEN TO WHITE MOTTLED CLAY (WEATHERED CLAYSTONE)
OFF-WHITE TO YELLOW BROWN, MEDIUM TO COARSE-GRAINED, POORLY CEMENTED SANDSTONE, GRADES WELL CEMENTED

HOLE COMPLETED 9/10/77
NO GROUND WATER ENCOUNTERED

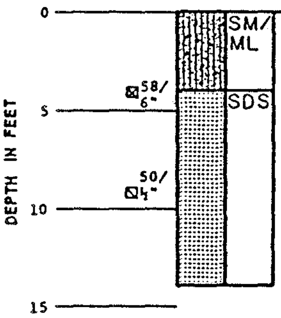
BORING NO. 27
EL. 5555.0 FT.



RED-BROWN FINE SAND AND SILT, LOOSE TO MEDIUM DENSE
GRADING CALCAREOUS WITH CALCITE STRINGERS
GREENISH, FINE TO MEDIUM-GRAINED SANDSTONE, VERY WELL-CEMENTED

HOLE COMPLETED 9/17/77
NO GROUND WATER ENCOUNTERED

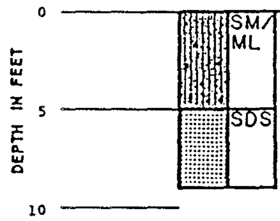
BORING NO. 24
EL. 5573.4 FT



RED-BROWN FINE SAND AND SILT, LOOSE TO MEDIUM DENSE
GRADING CALCAREOUS WITH CALCITE STRINGERS
OFF-WHITE, FINE GRAINED, WEATHERED SANDSTONE, GRADES WELL-CEMENTED
OFF-WHITE, FINE TO MEDIUM GRAINED, MODERATELY WELL-CEMENTED SANDSTONE
LIGHT BROWN, FINE TO MEDIUM GRAINED, WELL-CEMENTED SANDSTONE

HOLE COMPLETED 9/17/77
NO GROUND WATER ENCOUNTERED

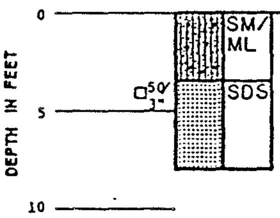
BORING NO. 29
EL. 5655.0 FT. (APPROX)



RED-BROWN FINE SAND AND SILT, LOOSE
GRADES MEDIUM DENSE
GRADING CALCAREOUS
WHITE TO SLIGHTLY TAN SANDSTONE
BECOMES WELL-CEMENTED

HOLE COMPLETED 9/30/77
NO GROUND WATER ENCOUNTERED

BORING NO. 26
EL. 5578.3 FT.

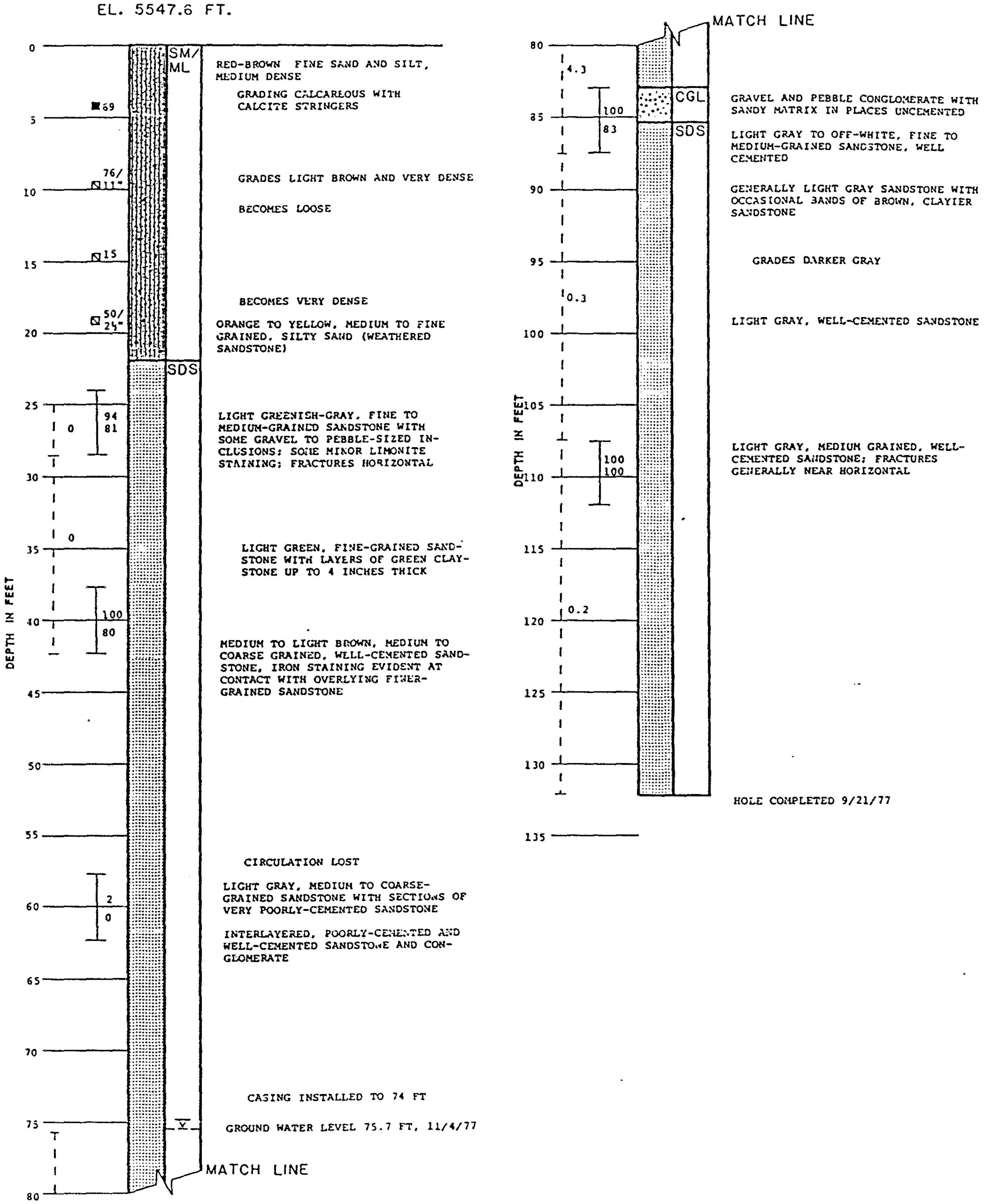


RED-BROWN FINE SAND AND SILT, LOOSE TO MEDIUM DENSE
GRADING CALCAREOUS WITH CALCITE STRINGERS
OFF-WHITE, FINE TO MEDIUM-GRAINED SANDSTONE, WEATHERED, GRADING WELL-CEMENTED
VERY WELL CEMENTED
HOLE COMPLETED 9/17/77
NO GROUND WATER ENCOUNTERED

LOG OF BORINGS

DAMES & MOORE

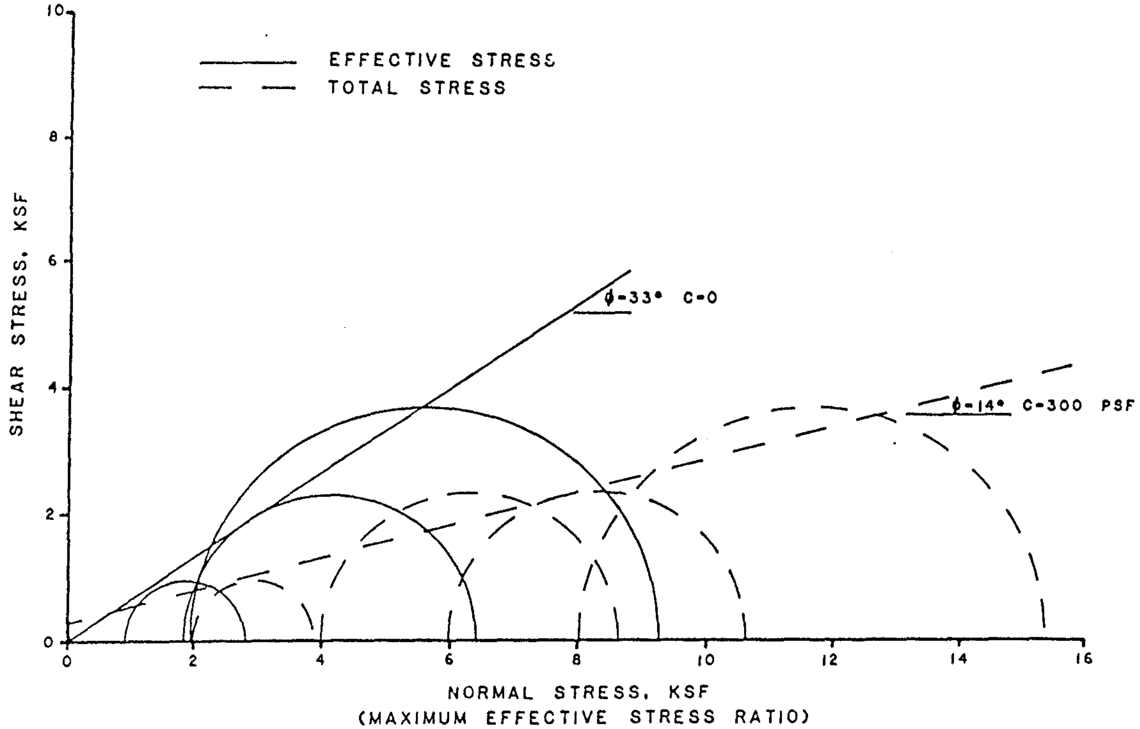
BORING NO. 28
EL. 5547.6 FT.



LOG OF BORINGS

DAMES & MOORE

TRIAXIAL COMPRESSION TESTS ON SILTY FINE SAND COMPACTED TO 95% OF AASHTO T-99 MAXIMUM DRY DENSITY



		①		②		③		④	
KEY		①		②		③		④	
BORING		19A		19A		19A		19A	
SAMPLE		1		2		3		4	
DEPTH (FEET)		Bulk		Bulk		Bulk		Bulk	
INITIAL	w, %	13.3		13.2		13.3		13.1	
	γ_d, PCF	111.1		111.2		111.1		111.3	
	e_o	0.529		0.527		0.528		0.526	
	% S	68 %		68 %		68 %		67 %	
FINAL	w, %	18.2		17.4		16.7		16.1	
	γ_d, PCF	114.7		117.1		117.0		120.5	
	e_f	0.481		0.450		0.451		0.409	
	% S	100 %		100 %		100 %		100 %	
BACK PRESSURE (PSI)		86.1		72.2		165		145	
STRAIN RATE (INCHES / MINUTE)		.000833		.000833		.000833		.000800	
STRESS CONDITION		PEAK $\sigma_1-\sigma_3$	MAX. $\bar{\sigma}_1/\bar{\sigma}_3$	PEAK $\sigma_1-\sigma_3$	MAX. $\bar{\sigma}_1/\bar{\sigma}_3$	PEAK $\sigma_1-\sigma_3$	MAX. $\bar{\sigma}_1/\bar{\sigma}_3$	PEAK $\sigma_1-\sigma_3$	MAX. $\bar{\sigma}_1/\bar{\sigma}_3$
TOTAL STRESS	ϵ, %	13.49	5.56	20.00	10.98	17.69	8.51	20.00	5.40
	TIME TO FAIL (MIN.)	960	396	1421	780	1261	635	1424	438
	σ_3, KSF	2.00	2.00	4.00	4.00	6.00	6.00	8.00	8.00
	$\sigma_1-\sigma_3$	2.98	1.88	5.68	4.59	5.12	4.57	11.68	7.37
	σ_1, KSF	4.98	3.88	9.68	8.59	11.12	10.57	19.68	15.37
	$\frac{1}{2}(\sigma_1-\sigma_3)$	1.24	0.94	2.84	2.29	2.53	2.29	5.84	3.63
	$\frac{1}{2}(\sigma_1+\sigma_3)$	3.24	2.94	6.84	6.30	8.59	8.28	13.84	11.69
	u, KSF	0.72	1.07	1.61	2.19	3.84	4.15	4.33	6.09
	A, $u/(\sigma_1-\sigma_3)$	0.29	0.57	0.28	0.48	0.75	0.91	0.37	0.83
EFFECTIVE STRESS	ϵ, %	13.49	5.56	20.00	10.98	17.69	8.51	20.00	5.40
	TIME TO FAIL (MIN.)	960	396	1421	780	1261	635	1424	438
	$\bar{\sigma}_3$, KSF	1.28	0.93	2.39	1.81	2.16	1.85	3.67	1.91
	$\bar{\sigma}_1-\bar{\sigma}_3$	2.48	1.88	5.68	4.59	5.12	4.57	11.68	7.37
	$\bar{\sigma}_1$, KSF	3.76	2.81	8.07	6.40	7.28	6.42	15.35	9.28
	$\frac{1}{2}(\bar{\sigma}_1-\bar{\sigma}_3)$	1.24	0.94	2.84	2.29	2.53	2.29	5.84	3.68
	$\frac{1}{2}(\bar{\sigma}_1+\bar{\sigma}_3)$	2.52	1.87	5.23	4.11	4.75	4.13	9.51	[illegible]
	u, KSF	0.72	1.07	1.61	2.19	3.84	4.15	4.33	6.09
	A, $u/(\bar{\sigma}_1-\bar{\sigma}_3)$	0.29	0.57	0.28	0.48	0.75	[illegible]	0.37	0.83
	$\bar{\sigma}_1/\bar{\sigma}_3$	2.94	3.01	3.38	[illegible]	3.38	3.47	4.19	4.86

TRIAXIAL COMPRESSION TEST REPORT

TYPE OF TEST CONSOLIDATED - UNDRAINED TRIAXIAL TEST WITH PORE PRESSURE MEASUREMENT

TYPE MATERIAL COMPACTED CORE

SAMPLE DESCRIPTION

CLASSIFICATION REDDISH - BROWN CLAYEY SILT

LIQUID LIMIT - PLASTIC LIMIT - SPECIFIC GRAVITY, G_s 2.70 (ALL)

PROJECT ENERGY FUELS

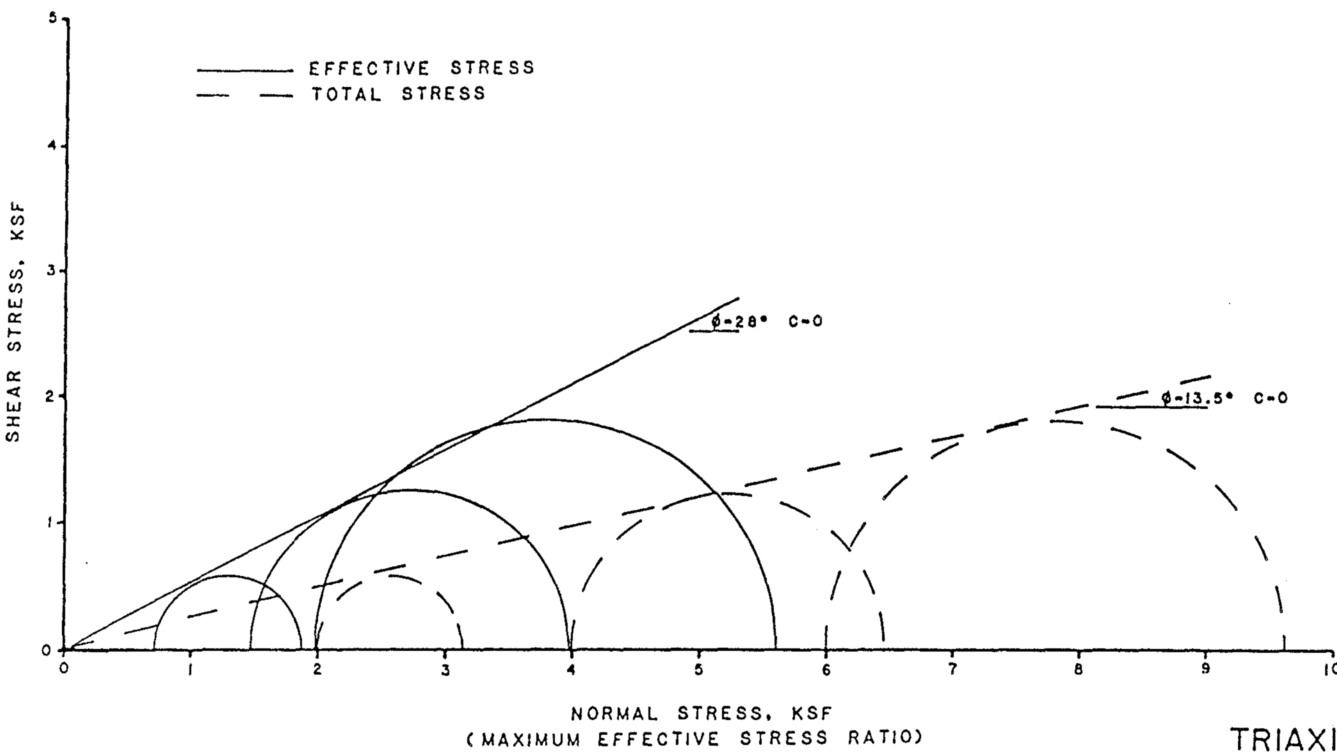
LOCATION DENVER

JOB NO. 9973-015-14 PREPARED BY RH , 10/27/77

CHECKED BY RH , 10/27/77

PLATE B-11

MULTI PHASE TRIAXIAL COMPRESSION TESTS ON SILTY FINE SAND AT NATURAL DENSITY



KEY		1		2		3	
BORING		14		14		14	
SAMPLE		1		1		1	
DEPTH (FEET)		4'		4'		4'	
INITIAL	w, %	3.2		19.7		17.7	
	γ_d, PCF	104.7		108.6		112.6	
	e_o	.5803		.5227		.4693	
	B	.15		1.0		1.0	
FINAL	w, %	19.7		17.7		17.6	
	γ_d, PCF	108.6		112.6		113.7	
	e_f	.5227		.4693		.4542	
	B	1.0		1.0		1.0	
BACK PRESSURE (PSI)							
STRAIN RATE (INCHES / MINUTE)							
STRESS CONDITION		PEAK $\sigma_1 - \sigma_3$	MAX $\bar{\sigma}_1/\bar{\sigma}_3$	PEAK $\sigma_1 - \sigma_3$	MAX $\bar{\sigma}_1/\bar{\sigma}_3$	PEAK $\sigma_1 - \sigma_3$	MAX $\bar{\sigma}_1/\bar{\sigma}_3$
TOTAL STRESS	ε, %	1.5	2.5	1.0	1.5	1.0	2.0
	TIME TO FAIL (MIN.)	15	25	10	15	10	19
	σ_3, PSF	2000	2000	4000	4000	6000	6000
	$\sigma_1 - \sigma_3$	1171	1160	2484	2467	3764	3628
	σ_1, PSF	3171	3160	6484	6467	9764	9624
	$\frac{1}{2}(\sigma_1 - \sigma_3)$	585	580	1242	1234	1882	1814
	$\frac{1}{2}(\sigma_1 + \sigma_3)$	2585	2580	5242	5234	7882	7812
	u, PSF	1166	1282	2318	2506	3442	4018
	A, $u/(\sigma_1 - \sigma_3)$	[illegible]	1.11	.933	1.02	.914	1.11
EFFECTIVE STRESS	ε, %	1.5	2.5	1.0	1.5	1.0	2.0
	TIME TO FAIL (MIN.)	15	25	10	1500	10	19
	$\bar{\sigma}_3$, PSF	834	718	1682	1494	2558	1982
	$\bar{\sigma}_1 - \bar{\sigma}_3$	1171	1160	2484	2467	3754	3628
	$\bar{\sigma}_1$, PSF	2005	1878	4166	3961	6322	5610
	$\frac{1}{2}(\bar{\sigma}_1 - \bar{\sigma}_3)$	585	580	1242	1234	1882	1814
	$\frac{1}{2}(\bar{\sigma}_1 + \bar{\sigma}_3)$	1420	1298	2924	2728	4440	3796
	u, PSF	1166	1282	2318	2506	3442	4018
	A, $u/(\bar{\sigma}_1 - \bar{\sigma}_3)$	.956	1.11	.933	1.02	.914	1.11
	$\bar{\sigma}_1/\bar{\sigma}_3$	2.40	2.62	2.48	2.65	2.47	2.83

TRIAXIAL COMPRESSION TEST REPORT

TYPE OF TEST Tx-CU-PP
TYPE MATERIAL Brn Silt & F. Sand

SAMPLE DESCRIPTION

CLASSIFICATION SM/ML
LIQUID LIMIT N/A PLASTIC LIMIT N/A SPECIFIC GRAVITY, G_s 2.65 assumed
PROJECT ENERGY Fuels
LOCATION Blanding UT.
JOB NO. 9973-015-14 PREPARED BY LWC, 11/21/77
CHECKED BY ______, / /

APPENDIX H

Material Quantities

Purpose: To determine the volume of riprap, clay, and random fill materials required to construct the uranium mill tailings cover at White Mesa Mill in Blanding, Utah.

Material volumes were calculated for two construction options:

- An integrated soil cover over Disposal Cells 2, 3, and 4A, and
- A cover over Cells 2 and 3, where Cell 4A tailings are excavated and placed in Cell 3.

Method: Standard geometric equations, as shown below, were used to determine the required material volumes.

Volume of a rectangle	= base * height * length
Volume of a trapezoid	= 1/2 * height *($base_1$ + $base_2$)

Surface area calculations for the tops of Cells 2, 3, and 4A are shown in Figure 1, and material volumes are calculated in Table 1.

The method for calculating material volumes on the side slopes is shown in Figure 2. The 5H:1V slopes have been divided into several zones which are indicated on Figure 1. The slopes have been categorized based on the average height they attain over a certain length. The height of the cover above the ground surface, along each side, was estimated using the cross sections in Figures 3 - 5. Calculations are presented in Table 2.

Assumptions:

- Random fill will be used to fill the existing freeboard space between the tailings and clay layer of the cover and bring the tailings pile elevations up to the berm elevations. This will create a smooth surface with a slope matching that of the cover. The random fill thickness between the clay and tailings surface will be a minimum of three feet. This random fill volume was not calculated due to the lack of information of the current topography in the tailings piles.

- The 0.2 percent slope on the tailings piles will be created using random fill materials beneath the clay layer of the cover. Cover materials will consist of one foot of clay under two feet of random fill . The top, riprap layer will consist of a minimum three inches on the top of the cover, and one foot on the side slopes.

Results:

Option 1: (Cover on Cells 2, 3, and 4A):

Total volume (Clay):	**=9,857,221 ft3**	**=365,082 yd3**
Total volume (Random fill):	**=19,918,351 ft3**	**=737,717 yd3**
Total volume (Riprap - top cover):	**=2,234,563 ft3**	**=82,762 yd3**
Total volume (Riprap - side slopes):	**=1,122,881 ft3**	**=41,588 yd3**

Option 2: (Cover on Cells 2 and 3):

Total volume (Clay):	**=7,816,884 ft3**	**=289,514 yd3**
Total volume (Random fill):	**=15,804,024 ft3**	**=585,334 yd3**
Total volume (Riprap - top cover):	**=1,754,563 ft3**	**=64,984 yd3**
Total volume (Riprap - side slopes):	**=968,890 ft3**	**=35,885 yd3**

TABLE 1
Volume of materials for top of cover:

Cell #	surface area ft^2				Th (riprap) inches	Th (fill) feet	Th (clay) feet					V (riprap)[1] ft.^3	V(fill)[1] ft.^3	V(clay)[1] ft.^3
2	3237500				3	2	1					809375	6475000	3237500
3	3780750				3	2	1					945188	7561500	3780750
4A	1920000				3	2	1					480000	3840000	1920000
Option 1 Total (Cells 2,3,and 4A):												**2234563**	**17876500**	**8938250**
Option 2 Total (Cells 2 and 3):												**1754563**	**14036500**	**7018250**

TABLE 2
Volume of materials for side slopes:

Slope #	total h ft.	h (riprap) ft.	h (fill) ft.	h (clay) ft.	L' (riprap) ft.	L' (fill) ft.	L' (clay) ft.	Length ft.	Th (riprap) feet	Th (fill) feet	Th (clay) feet	V(riprap)[2] ft.^3	V(fill)[2] ft.^3	V(clay)[2] ft.^3
1	16	15.5	14.0	12.5	79.0	71.4	63.7	3500	1	2	1	276622	499704	223082
2	6	5.5	4.0	2.5	28.0	20.4	12.7	500	1	2	1	14022	20396	6374
3	6	5.5	4.0	2.5	28.0	20.4	12.7	1180	1	2	1	33093	48135	15042
4	20	19.5	18.0	16.5	99.4	91.8	84.1	1900	1	2	1	188919	348773	159854
5	43	42.5	41.0	39.5	216.7	209.1	201.4	1750	1	2	1	379240	731709	352470
6	10	9.5	8.0	6.5	48.4	40.8	33.1	950	1	2	1	46019	77505	31486
7	5	4.5	3.0	1.5	22.9	15.3	7.6	1350	1	2	1	30977	41302	10326
8	27	26.5	25.0	23.5	135.1	127.5	119.8	1200	1	2	1	162149	305941	143792
9	35	34.5	33.0	31.5	175.9	168.3	160.6	1450	1	2	1	255078	487976	232898
10	18	17.5	16.0	14.5	89.2	81.6	73.9	1300	1	2	1	116003	212119	96117
Option 1 Total (Slopes 1, 2, 3, 4, 6, 7, 8, 9, and 10):												**1122881**	**2041851**	**918971**
Option 2 Total (Slopes 1, 2, 3, 4, 5, 6, and 7):												**968890**	**1767524**	**798634**

TABLE 3
Total Material Volumes for the Cover

Option 1:			
	riprap (top of cover)	2234563 ft^3	82762 yd^3
	riprap (side slopes)	1122881 ft^3	41588 yd^3
	random fill	19918351 ft^3	737717 yd^3
	clay	9857221 ft^3	365082 yd^3
Option 2:			
	riprap (top of cover)	1754563 ft^3	64984 yd^3
	riprap (side slopes)	968890 ft^3	35885 yd^3
	random fill	15804024 ft^3	585334 yd^3
	clay	7816884 ft^3	289514 yd^3

Notes:
Riprap on top and sides of cover are of different dimensions, and are therefore caluculated separately.
Total h = the average height along the slope length.
Th = Thickness of the layer of material.
V = Total volume of the material
L' = Length of the layer down the side slope. Calculated as (h(material)) / (cos 78.7). The slope is 5H:1V.
Length = Horizontal length of the side slope.

(1) Volume calculated as (surface area) x (layer thickness).
(2) Volume calculated as (L' x Th x Length).

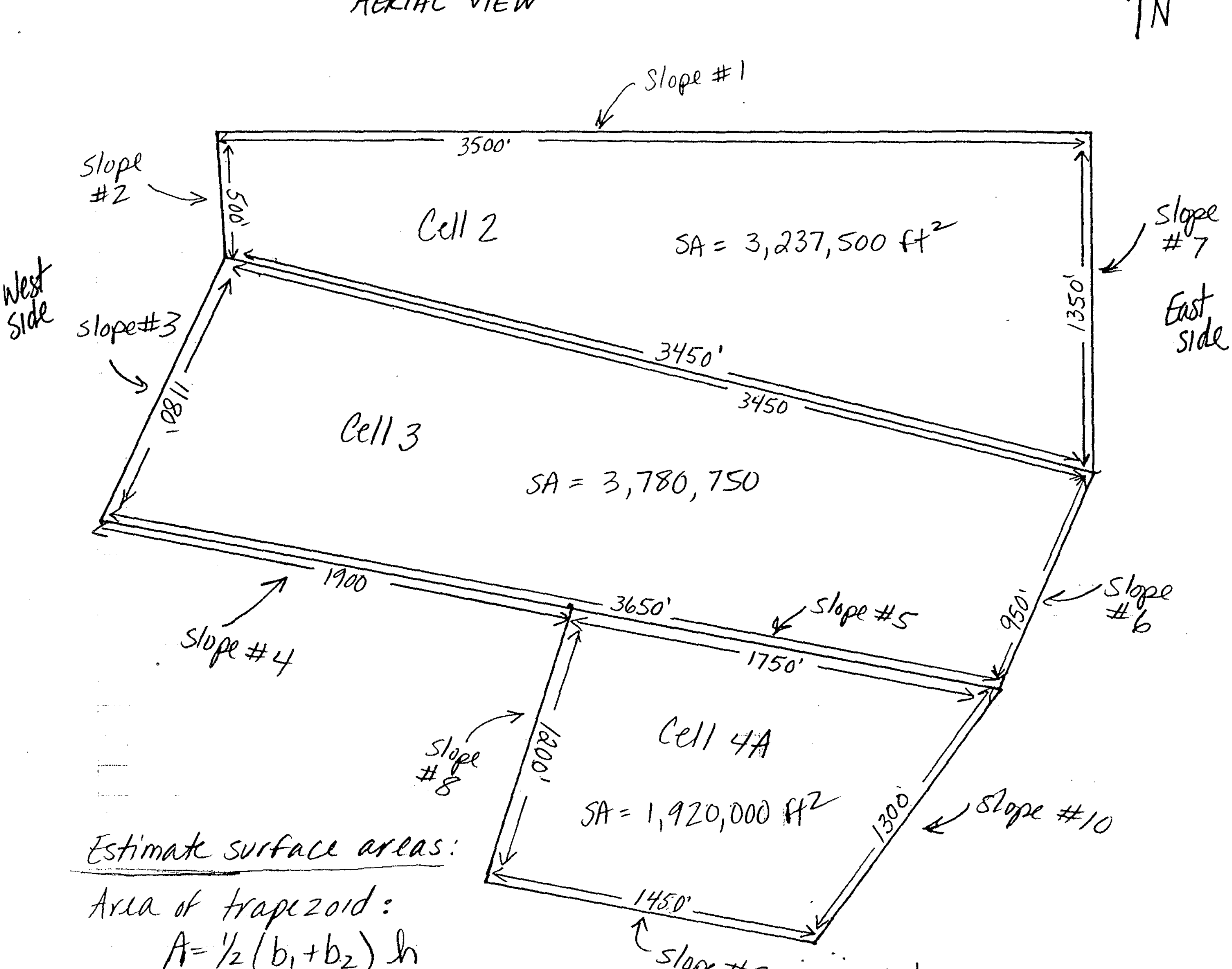
TITAN Environmental

By PJA Date ____ Subject ____ Sheet No 4 of 8

Chkd by KG Date 8/14 Proj No ____

1/5" × 1/5"

Surface Areas of Cells
AERIAL VIEW



Estimate surface areas:

Area of trapezoid:

$A = \frac{1}{2}(b_1 + b_2)h$

Area of parallelogram:

$A = bh$

Cell #2

$A = \frac{1}{2}(1350' + 500') \times 3500' = 3,237,500 \text{ ft}^2$

Cell #3

$A = (3550 \times 1065) = 3,780,750 \text{ ft}^2$

Cell #4A

$A = \frac{1}{2}(1450 + 1750) \times 1200 = 1,920,000 \text{ ft}^2$

Totals

1) Option #1
Cells 2, 3, 4A:
8,938,250

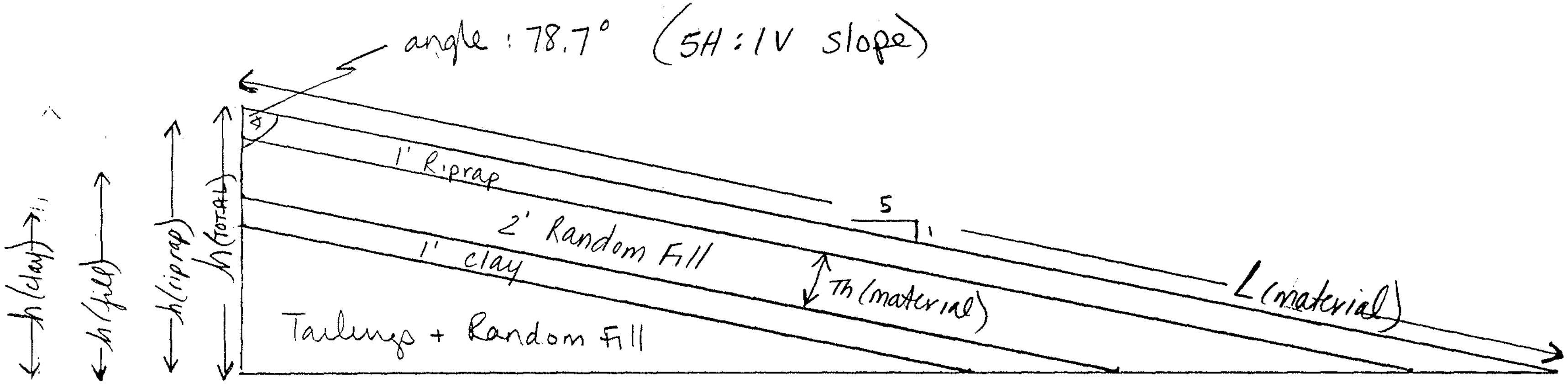
2) Option #2
Cells 2, 3:
7,018,250 ft²

Figure 1

TITAN Environmental

By GJA Date ______ Subject ______ Sheet No 5 of 8
Chkd by KG Date 8/14 ______ Proj No ______
1/5" × 1/5"

Volumes of Materials along side slopes



L = length of material layer down side slope

$$\cos \measuredangle = \frac{h\,(\text{material})}{L\,(\text{material})}$$

$$L\,(\text{material}) = \frac{h\,(\text{material})}{\cos 78.7}$$

$$V\,(\text{material}) = L\,(\text{material}) \times Th\,(\text{material}) \times \text{Length (from aerial view)}$$

Example: For $h_{TOTAL} = 16$ ft. (slope #1)

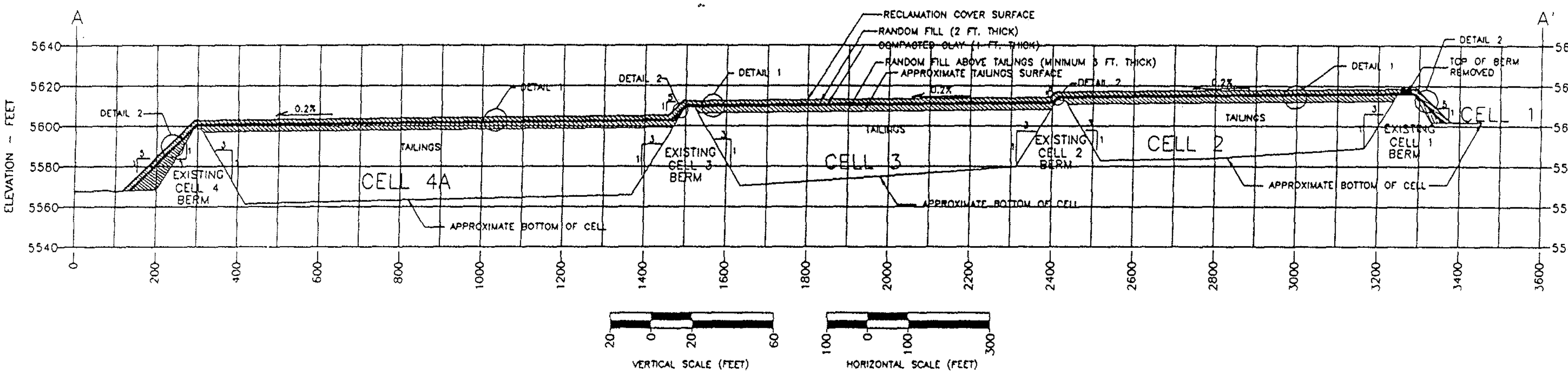
$h_{riprap} = 16$ ft. $- 0.5$ ft. $= 15.5$ ft.

$$L_{riprap} = \frac{15.5 \text{ ft}}{\cos 78.7} = 79.0 \text{ ft.}$$

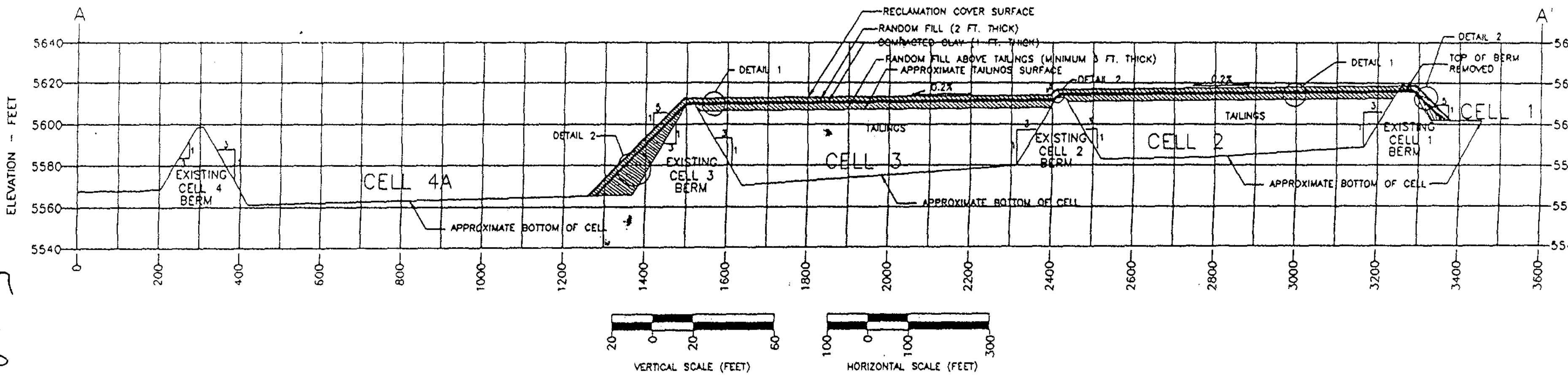
$$V_{riprap} = (79.0')(1.0')(3500') = \underline{276{,}500 \text{ ft}^3}$$

Figure 2

Figure 2



SECTION A–A' (WITH COVER ON CELLS 2, 3 & 4A)



SECTION A–A' (WITH COVER ON CELLS 2 & 3)

Figure 4

Figure 4

1 of 2

REFERENCES

Advanced Terra Testing, 1996, Physical soil data, White Mesa Mill, Blanding, Utah, July 25, 1996.

Aitken, George W. and R. L. Berg, 1968, "Digital Solution of Modified Berggren Equation to Calculate Depths of Freeze or Thaw in Multilayered Systems", Special Report 122, October.

Chen and Associates, 1978, "Soil Property Study Earth Lined Tailings Retention Cells White Mesa Uranium Project, Blanding, Utah", July 18.

Chen and Associates, 1979, "Soil Property Study Proposed Tailings Retention Cells White Mesa Uranium Project, Blanding, Utah", January 23.

Dames and Moore, 1978, "Environmental Report, White Mesa Uranium Project, San Juan County, Utah", January 30.

Energy Fuels Nuclear, Inc., 1996, radon flux measurements for 1994 and 1995.

Environmental Protection Agency (EPA), 1994, "The Hydrologic Evaluation of Landfill Performance (HELP) Model, Version 3", EPA/600/R-94/168b, September.

Freeze, R. Allan and J. A. Cherry, 1979, "Groundwater".

Mitre Software Corporation, 1990, "GSLOPE Limit Equilibrium Slope Stability Analysis", Alberta, Canada, June 1.

Nuclear Regulatory Commission (NRC), 1989, "Regulatory Guide 3.64 (Task WM-503-4) Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers", March.

NRC, 1990, "Final Staff Technical Position Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailings Sites", August.

NUREG/CR-4620, Nelson, J.D., Abt, S.R., et al, 1986, "Methodologies for Evaluating Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments", June.

NUREG/CR-4651, 1987, "Development of Riprap Design Criteria by Riprap Testing in Flumes: Phase 1", May.

Perry, Robert H. et al, 1984, "Perry's Chemical Engineers' Handbook", McGraw-Hill, Inc.

Principles & Practice of Civil Engineering, 2nd Edition, 1996.

Rogers and Associates Engineering Company, 1988, Radiological Properties Letters to C.O. Sealy from R.Y. Bowser dated March 4 and May 9.

Rogers and Associates Engineering Company, 1996, Report of Radiological Property Measurements, September 3, 1996.

U.S. Department of Energy, 1988, "Effect of Freezing and Thawing on UMTRA Covers" Albuquerque, New Mexico, October.