Project #336
October 1993

SMI
Shepherd Miller, Inc.

Report

Western Nuclear, Inc. Split Rock Mill October 1993 - Revision No. 5 to the June 30, 1987 Uranium Tailings Reclamation Plan

Split Rock Mill Site
Jeffrey City, Wyoming

Prepared for:

Western Nuclear, Inc.
Lakewood, Colorado

Volume 3 of 3

40-1162

Report

Western Nuclear, Inc. Split Rock Mill October 1993 - Revision No. 5 to the June 30, 1987 Uranium Tailings Reclamation Plan

w/ ltr 10/29/93
94-0051

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LIST OF APPENDICES

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APPENDIX E

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SOIL/ROCK MATRIX DESIGN CALCULATIONS
WESTERN NUCLEAR, INC.

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SOIL\ROCK MATRIX DESIGN CALCULATION
WESTERN NUCLEAR, INC.

PURPOSE. As agreed by Western Nuclear, Inc. (WNI) and the NRC, a soil\rock matrix will be used as the top erosion protection layer at the Split Rock Mill. This layer overlies the borrow soil layer which in turn overlies the cody shale radon barrier and tailing. The matrix will consist of a rock mulch layer overlain by a thin borrow soil layer which will be compacted into the rock mulch. The purpose of these calculations is to determine the required rock size and layer thickness of the rock mulch. The gradation for the rock mulch is also included in this calculation brief.

METHOD. The methods described in the NRC's Final Staff Technical Position will be used to determine the size and thickness of the rock mulch. Since no method exists for conservative design of a soil/rock matrix, and as indicated in the STP, a soil/rock matrix has similar or better stability characteristics as the rock layer alone (i.e. without soil), the rock layer will be evaluated alone thus adding some conservatism to the design. The soil/rock matrix for the areas inside the diversion ditches was designed differently than the soil/rock matrix located outside the diversion ditches.

The design procedure for the soil/rock matrix inside the diversion ditches is as follows:

1) Locate several profiles on the tailing cover such that these profiles form a representative model of the range of slopes on the impoundment. Include worst case scenarios (i.e. steepest slopes) for rock mulch sizing purposes. Divide each of the profiles into segments with relatively constant slopes. The locations of the profiles are shown on Figure E.1.1 (page E-11).

2) Run each slope segment from each profile through the Safety Factors Method overland flow spreadsheet (for slopes less than 10%) or the Stephenson's Method overland flow spreadsheet (for slopes greater than or equal to 10%). These spreadsheets calculate the required D50 of the rock comprising the matrix.

Profile #1, Slope Segment #1 = 550 ft

Profile #1, Slope segment #2 = 550 + 415 = 960 ft.

Profile #1, Slope segment #3 = 550 + 415 + 275 = 1245 ft.

Profile #1, Slope segment #4 = 550 + 415 + 275 + 250 = 1510 ft.

Profile #1, Slope segment #5 = 550 + 415 + 275 + 250 + 550 = 2060 ft.

As discussed in the following paragraph, the time of concentration is calculated separately and manually input for Tc (actual).

The time of concentration (Tc) is calculated for each slope segment. The Tc of slope segments which are downgradient from other slope segments along the same profiles, are calculated by adding the Tc's from all slope segments located upstream from the segment in questions.

3) Based on the calculated rock sizes, determine the design rock size and develop an appropriate gradation envelope. The rock mulch gradation requirements are determine in the same manner as the diversion channel riprap gradation development described in Appendix C, section C.3.

These calculations were completed on spreadsheets and are attached. Sample calculations are also attached for clarification of the methods used.

The design procedure for the soil/rock matrix outside the diversion ditches is as follows:

1) Locate the "worst case" area outside of the ditches to design the soil/rock matrix. This is determined based on slope and length and is shown on Figure E.1.2 (page E-12).

2) Using HEC-1 and the procedures set forth in Appendix B, determine the flow over the "worst case" area.

3) Size the soil/rock matrix using Stephenson's Method for rock fill on steep slopes.

These calculations are attached.

RESULTS. The results of the rock sizing calculations are presented in Table E.1.1 (page E-8) and Table E.1.2 (page E-9). A uniform rock D_{50} of two (2) inches was chosen for the soil\rock matrix. This size rock exceeds the minimum criteria in all areas of the tailing cover. The rock mulch gradation required for a D_{50} of two (2) inches is presented in Figure E.1.2 (page E-12).

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REFERENCES

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

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

U.S. Nuclear Regulatory Commission (NRC), "Final Staff Technical Position Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailing Sites," 1990.

E 1

TABLES

Table E.1.1

Rock Mulch Sizing Results Inside of Ditches

PROFILE	SEGMENT	SLOPE LENGTH (ft)	TOTAL LENGTH (ft)	AVERAGE SLOPE (ft/ft)	FLOW VELOCITY (fps)	D50 (in)
1	1	550	550	.044	3.32	0.54
	2	415	965	.034	3.89	0.62
	3	275	1240	.095	4.75	1.97
	4	250	1490	.040	4.58	0.96
	5	550	2040	.022	4.74	0.68
2	1	275	275	.051	2.67	0.39
	2	965	1240	.033	4.21	0.71
	3	210	1450	.048	4.63	1.12
	4	1520	2970	.012	3.51	0.72
3	1	140	140	.050	2.12	0.25
	2	140	280	.029	2.51	0.23
	3	1040	1320	.010	2.57	0.36
4	1	275	275	.011	1.56	0.14
	2	1245	1520	.008	2.56	0.34
5	1	210	210	.048	2.42	0.31
	2	725	935	.014	2.47	0.38
	3	415	1350	.019	2.98	0.62
6	1	690	690	.030	3.42	0.44

Table E.1.2
Rock Mulch Sizing Results Outside of Ditches

LOCATION	FLOW (cfs)	AREA (acres)	REQUIRED D_{50} (in)
SEE FIGURE E.1.2	24	0.6135	1.1

FIGURES

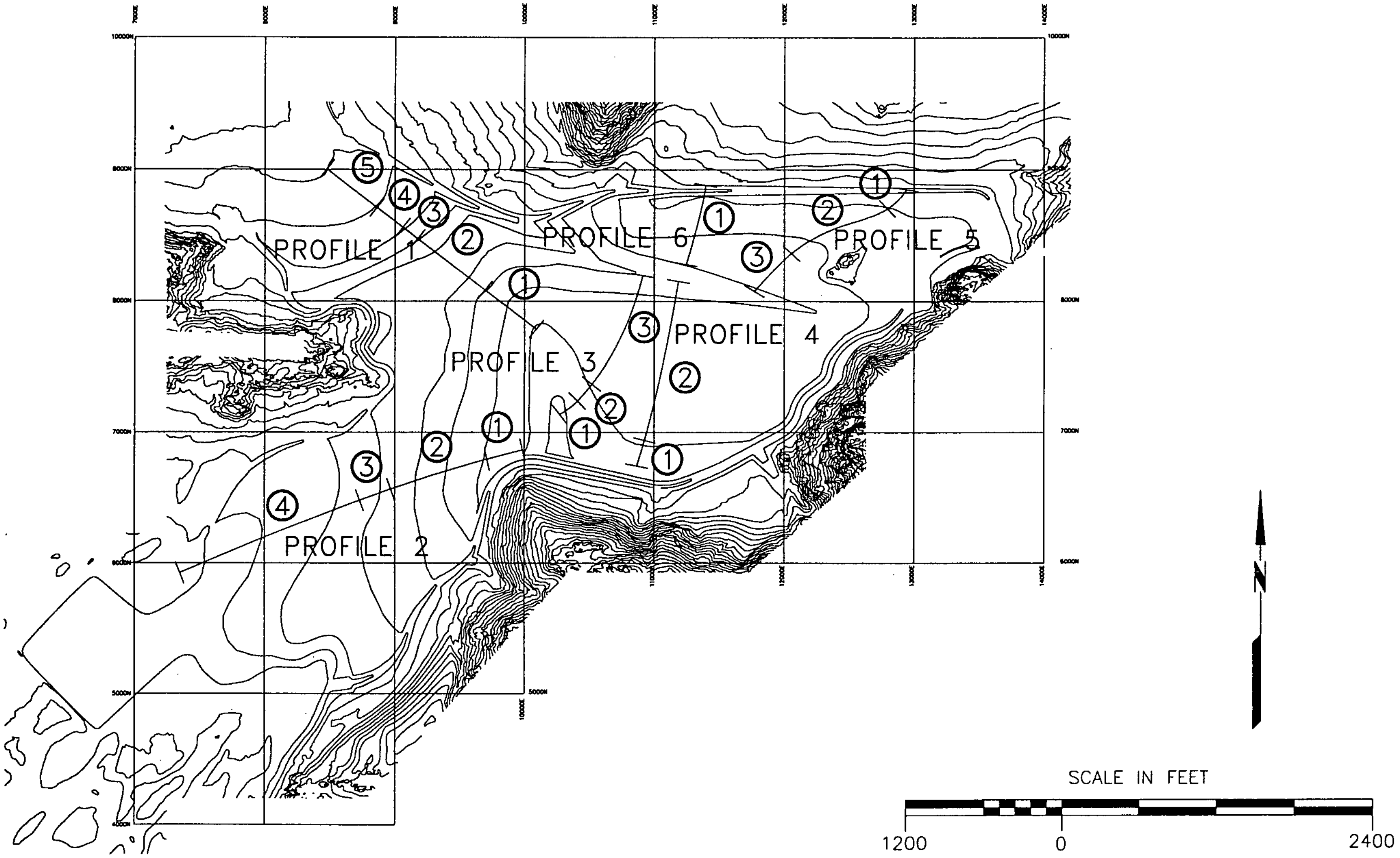

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FIGURE E.1.1
PROFILE LOCATIONS INSIDE OF DITCHES

Date: OCT., 1993
Project: 336
File: ROCK

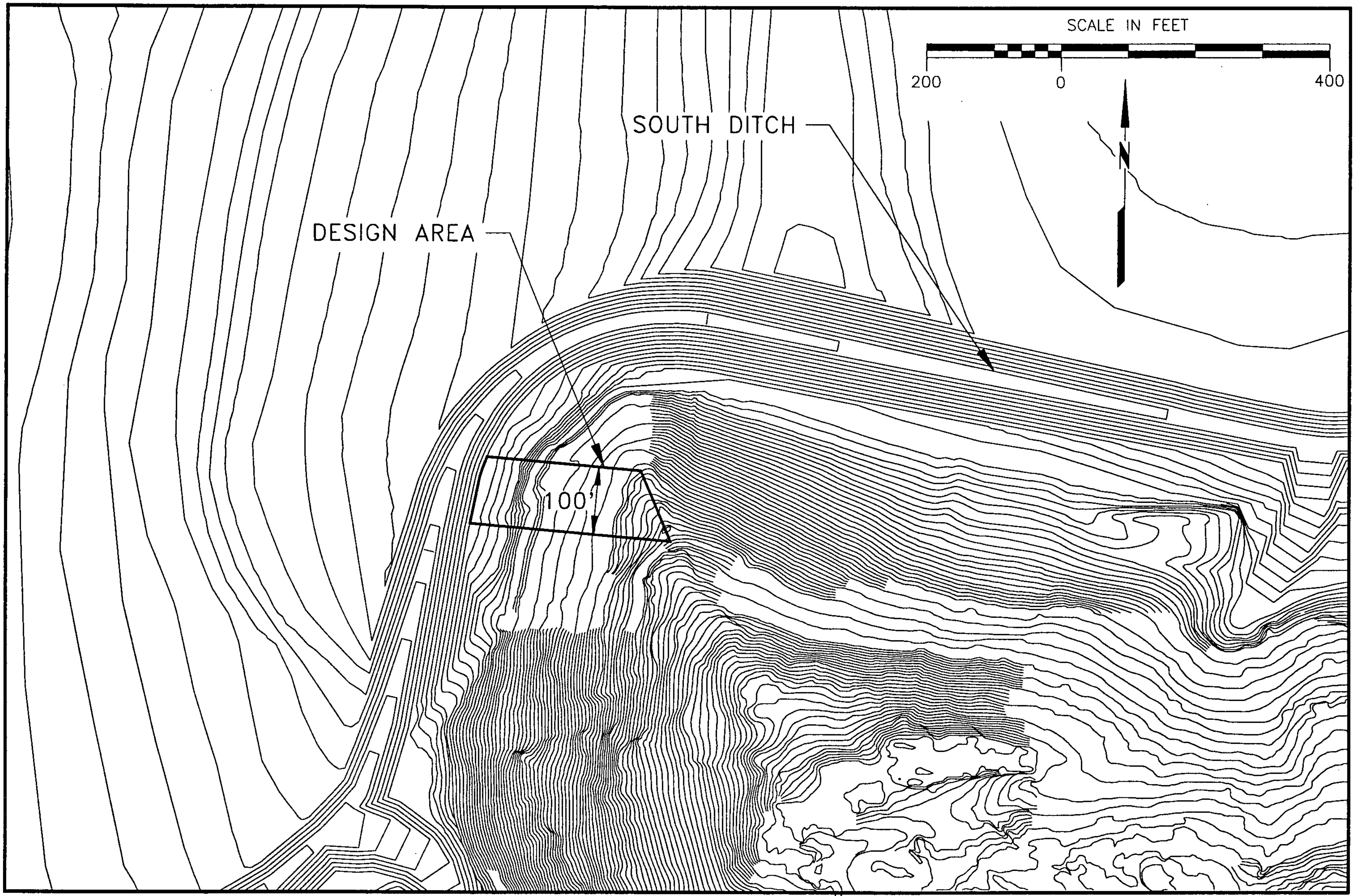

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FIGURE E.1.2
ROCK DESIGN LOCATION AREA
OUTSIDE OF DITCHES

Date:	OCT., 1993
Project:	336
File:	STABLE

E/2

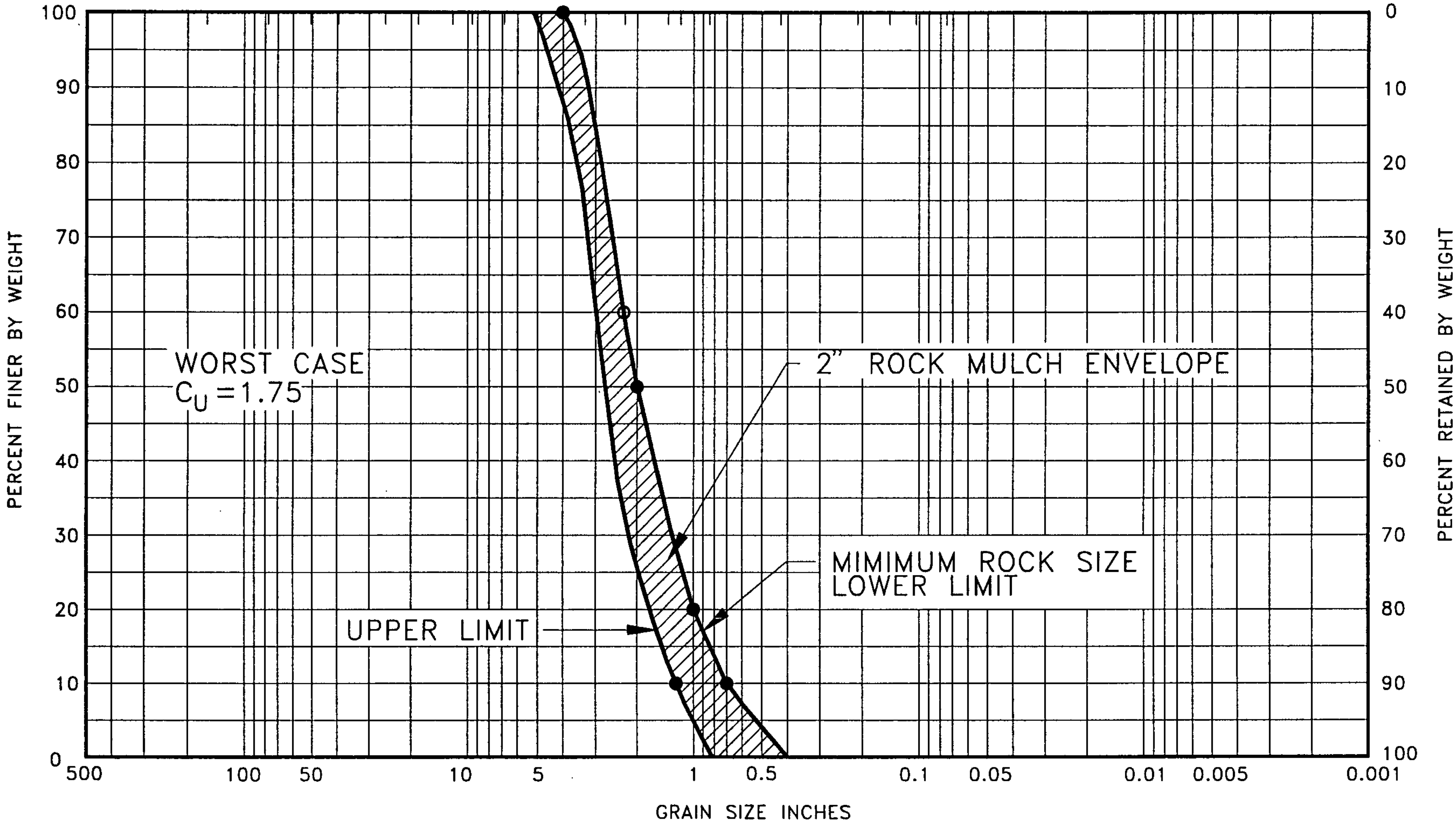

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FIGURE E.1.3
ROCK MULCH GRADATION

Date:	OCT., 1993
Project:	336
File:	GSD-10

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SAMPLE CALCULATIONS FOR AREAS INSIDE THE DIVERSION DITCHES

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By Dwm Date 2-4-92 Subject ROCK ARMOR Sheet No. 9 of 44
Chkd. By PEC Date 2-15-92 SAMPLE CALCULATION Proj. No. 91-225-06
1/4" X 1/4"

SAMPLE CALCULATION OF d_{50} USING SAFETY FACTORS METHOD - OVERLAND FLOW

THE SAFETY FACTORS METHOD USES THE FOLLOWING FORMULAE TO SIZE ROCK ARMOR ON THE IMPOUNDMENT TOP:

$$SF = \frac{\cos\alpha \tan\phi}{\eta \tan\phi + \sin\alpha}$$

where

SF = SAFETY FACTOR
α = SLOPE OF IMPOUNDMENT TOP IN DEGREES FROM HORIZONTAL

ϕ = ANGLE OF REPOSE OF ROCK ARMOR
- ASSUME $\phi = 41^\circ$ (SEE FIGURE 3.2 OF NUREG 4651 (REFERENCE #1)

FOR NON-TURB. FLOWS ⇒ $\eta = \frac{21 t_o}{(G_s - 1)\gamma d_{50}}$ where $t_o = \gamma d s$ = AVERAGE TRACTI FORCE ON PLAN CONTAINING THE PARTICLE

where γ = spec. wt. of water
d = depth of flow (ft)
s = slope in ft/ft

G_s = spec. grav. of Rock
D_{50} = median dia of rock

FOR A PMF CALCULATION, THE SF SHOULD BE AT OR JUST ABOVE 1.0. THUS WE CAN REARRANGE THE ABOVE EQUATIONS TO SOLVE DIRECTLY FOR D_{50}.

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CanonieEnvironmental

By Date 2-9-92 Subject ROCK ARMOR Sheet No. 10 of 44
Chkd. By PEC Date 2-15-92 SAMPLE CALCULATION Proj. No. 91-225-06
1/4" X 1/4"

$$SF = \frac{\cos\alpha \tan\phi}{n \tan\phi + \sin\alpha}$$

$$n\tan\phi + \sin\alpha = \frac{\cos\alpha \tan\phi}{SF}$$ (CROSS-MULTIPLY)

$$n\tan\phi = \frac{\cos\alpha \tan\phi}{SF} - \sin\alpha$$ (SUBTRACT $\sin\alpha$)

$$y = \frac{\cos\alpha \tan\phi}{SF} - \sin\alpha$$ (ASSIGN y)

$$\therefore \; n\tan\phi = y$$ (SUBSITUTE y)

$$\frac{21 t_o}{(G_s - 1)\gamma(d_{50})} \tan\phi = y$$ (SUBSTITUTE n)

$$X = \frac{21 t_o}{(G_s - 1)\gamma}$$ (ASSIGN x)

$$1/d_{50} \, (x)(\tan\phi) = y$$ (SUBSTITUTE x)

$$\frac{x(\tan\phi)}{y} = d_{50}$$ (CROSS MULTIPLY)

$$d_{50} = \frac{x \tan\phi}{y}$$ (REARRANGE AND WRITE OUT)

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CanonieEnvironmental

By sum Date 2-4-92 Subject Rock Armor Sheet No. 11 of 44

Chkd. By PEC Date 2-15-92 Sample Calc - Cont. Proj. No. 91-225-06

1/4" X 1/4"

$$\therefore \quad d_{50} = \frac{\left[\frac{21 t_0}{(G_s - 1)\gamma} (\tan \phi)\right]}{\left[\frac{\cos\alpha \tan\phi}{SF} - \sin\alpha\right]}$$

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COMPUTED BY JGC

CALCULATE d_{50} FOR ROCK MULCH IN AREA OF PROFILE #1, SLOPE SEGMENT #1

ASSUME:
RUNOFF COEFF = 0.8 - NRC RECOMMENDED VALUE
FLOW CONCENTRATION FACTOR = 1
SPECIFIC GRAVITY OF ROCK = 2.65
FRICTION ANGLE OF ROCK = 41° = ϕ
SAFETY FACTOR = 1.0

KNOWN:
SLOPE LENGTH = 550 ft (FIG E.1.1)
AVG. SLOPE = 4.4% OR .044 ft/ft (FIG E.1.1)
PMP (1 hr) = 9.2 INCHES (APP. B)

CALCULATIONS:

DRAINAGE AREA (UNIT WIDTH) = SLOPE LENGTH * 1 ft

$$= \left(550\text{ ft} \Big/ 43560\tfrac{\text{ft}^2}{\text{ACRE}} \right) * 1\text{ ft}$$

$$\underline{\underline{= .0126 \text{ ACRES}}}$$

TIME OF CONCENTRATION (t_c)

$$= 0.00013 \left(\frac{L^{0.77}}{S^{0.385}} \right) \quad \text{(EQ. 4.44 NUREG 4620)}$$

$$= 0.00013 \left(\frac{550^{.77}}{.044^{.385}} \right)$$

$$= .0558 \text{ HOURS}$$

$$= \underline{\underline{3.35 \text{ MINUTES}}}$$

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CALCULATIONS (CONT):

% OF 1-HR PRECIPITATION:

HMR-55A

Table 12.4.—Percent of 1-hr local-storm PMP for selected durations for 6-/1-hr ratio of 1.35 (HMR No. 49)

Duration (hr)	Percent of 1 hr
1/4	.68
1/2	.86
3/4	.94
1	1.00
2	1.16
3	1.23
4	1.28
5	1.32
6	1.35

FROM TABLE 12.4 FROM HMR55A – DRAINAGE BASIN BETWEEN CONTINENTAL DIVIDE AND 103RD MERIDIAN – SAME DATA USED IN PMF CALC. –

SINCE T_c'S ARE TYP < 15 MIN AND MAJORITY OF PPT. OCCURS WITHIN 1ST 15-MIN

USE LINEAR INTERPOLATION TO DETERMINE "% OF 1 HR PPT."

FROM ABOVE TABLE:

$$\frac{3.35-0}{15-0} = \frac{X-0}{68-0} \qquad \underline{\underline{X = 15.19\%}}$$

AMT. OF PPT (REDUCED):

$$(9.2 \text{ INCHES}) \times (15.19) = \underline{\underline{1.40 \text{ INCHES}}}$$

PPT. INTENSITY:

$$\text{PPT. INTENSITY} = \text{PPT. AMOUNT (REDUCED)} / T_c \times \frac{60 \text{ MIN}}{\text{HR}}$$

$$= (1.40'') / 3.35 \text{ MIN} \times \frac{60 \text{ MIN}}{\text{HR}}$$

$$= \underline{\underline{25.07 \text{ INCHES/HOUR}}}$$

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CALCULATIONS (CONT):

MANNINGS n:

$$n = 0.0395 (d_{50})^{0.1667}$$ ANDERSON'S METHOD FOR SLOPES < 2%

$$n = 0.0456 (d_{50} S)^{0.159}$$ CSU METHOD FOR SLOPES > 2%

NOTE: n IS ASSUMED IN THIS METHOD AND ITERATED UNTIL THE n CALCULATED ABOVE EQUALS THE n ASSUMED. THIS IS DUE TO THE FACT THAT n_{calc} IS A FUNCTION OF d_{50} AND d_{50} IS A FUNCTION OF DEPTH WHICH IS FUNCTION OF n.

PEAK DISCHARGE:

$$Q = CiA = 0.8 (25.07)(.0126)$$

$$\underline{\underline{Q = 0.253 \text{ cfs}}}$$

CONC. DISCHARGE:

$$= QC = 0.253(1) = \underline{\underline{0.253 \text{ cfs}}}$$

(C = 1.0 AS PER RAY GONZALES OF NRC)

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CALCULATIONS (CONT):

DEPTH: (DETERMINE USING MANNING'S EQN ASSUMING UNIT AREA)

$$= \left[\frac{Qn}{1.486 S^{1/2}}\right]^{3/5} = \left[\frac{(0.253)(.0169)}{1.486(.044)^{1/2}}\right]^{3/5}$$

$$= \underline{\underline{.076 \text{ FT}}}$$

TRACTIVE FORCE:

= (SPEC. GRAVITY OF H_2O)(DEPTH)(AVG SLOPE)

= (62.4)(.076)(.044)

$= \underline{\underline{.208 \text{ psf}}}$

FLOW VELOCITY:

$$= \frac{\text{CONC. DISCHARGE}}{\text{DEPTH}} = \frac{.253}{.076} = \underline{\underline{3.33 \text{ fps}}}$$

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CALCULATIONS (CONT):

$$d_{50} = \frac{\left[\frac{21\,\tau_0}{(G_s-1)\gamma}(\tan\phi)\right]}{\left[\frac{\cos\alpha\,\tan\phi}{SF} - \sin\alpha\right]}$$

$$= \frac{\frac{(21)(62.4)(.076)(.044)}{(2.65-1)(62.4)}(\tan 41)}{\frac{(\cos 0.044)(\tan 41)}{1.0} - (\sin 0.044)}$$

$$= \frac{.0364}{.869} = .042\text{ ft.}$$

$$d_{50} = .042\text{ ft} = .5\text{ inches}$$

NOTE: MINOR DISCREPANCIES IN SPREADSHEETS ARE DUE TO SIGNIFICANT FIGURES.

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ROCK MULCH GRADATION CALCULATIONS

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ROCK MULCH GRADATION

DETERMINE D_{MAX}, D_{20} AND D_{10} OF ROCK MULCH

$D_{MAX} = 4"$ ⇒ $D_{MAX} = 2 D_{50}$

$D_{50} = 2"$ ⇒ CALCULATED → SEE SPREADSHEETS

$D_{20} = 1.0"$ ⇒ $D_{20} = D_{50}/2$

$D_{10} = 0.7"$ ⇒ $D_{10} = D_{50}/3$

ROCK MULCH ENVELOPE DEVELOPMENT

PLOT GRADATION ON SEMI-LOG PAPER. DEVELOP ENVELOPE FOR CONSTRUCTION FLEXIBILITY WHILE MAINTANING A WELL GRADED GRADATION.

THE CORPS OF ENGINEERS RECOMMEND A UNIFORMITY COEFFICIENT (C_u) OF ≥ 1.75 FOR A WELL GRADED RIPRAP [NUREG 4651]. THIS WILL BE USED AS A GUIDE IN DEVELOPING THE ENVELOPES.

THE GRADATION IS PRESENTED ON FIGURE E.1.2.

SPREADSHEET CALCULATIONS
FOR AREAS INSIDE THE DIVERSION DITCHES

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TIME OF CONCENTRATION CALCULATION SPREADSHEETS

SPREADHEET FOR CALCULATING TIME TO CONCENTRATION

PROJECT: SMI 336 - JEFFREY CITY FILE R:\PROJECTS\335\QP\TIMECONC.WQ1

PROFILE #1

SLOPE SEGMENT	LENGTH OF SLOPE SEGMENT (FEET)	SLOPE OF SLOPE SEGMENT (FT/FT)	TIME OF CONCENTRATION (MIN)	TOTAL TIME OF CONCENTRATION (MIN)
1	550	0.044	3.345	3.345
2	415	0.034	2.974	6.320
3	275	0.095	1.459	7.778
4	250	0.04	1.891	9.669
5	550	0.022	4.369	14.038

PROFILE #2

SLOPE SEGMENT	LENGTH OF SLOPE SEGMENT (FEET)	SLOPE OF SLOPE SEGMENT (FT/FT)	TIME OF CONCENTRATION (MIN)	TOTAL TIME OF CONCENTRATION (MIN)
1	275	0.051	1.853	1.853
2	965	0.033	5.762	7.615
3	210	0.048	1.541	9.157
4	1520	0.012	12.068	21.224

PROFILE #3

SLOPE SEGMENT	LENGTH OF SLOPE SEGMENT (FEET)	SLOPE OF SLOPE SEGMENT (FT/FT)	TIME OF CONCENTRATION (MIN)	TOTAL TIME OF CONCENTRATION (MIN)
1	140	0.05	1.110	1.110
2	140	0.029	1.370	2.480
3	1040	0.01	9.665	12.145

PROFILE #4

SLOPE SEGMENT	LENGTH OF SLOPE SEGMENT (FEET)	SLOPE OF SLOPE SEGMENT (FT/FT)	TIME OF CONCENTRATION (MIN)	TOTAL TIME OF CONCENTRATION (MIN)
1	275	0.011	3.345	3.345
2	1245	0.008	12.097	15.443

PROFILE #5

SLOPE SEGMENT	LENGTH OF SLOPE SEGMENT (FEET)	SLOPE OF SLOPE SEGMENT (FT/FT)	TIME OF CONCENTRATION (MIN)	TOTAL TIME OF CONCENTRATION (MIN)
1	210	0.048	1.541	1.541
2	725	0.014	6.431	7.973
3	415	0.019	3.721	11.694

PROFILE #6

SLOPE SEGMENT	LENGTH OF SLOPE SEGMENT (FEET)	SLOPE OF SLOPE SEGMENT (FT/FT)	TIME OF CONCENTRATION (MIN)	TOTAL TIME OF CONCENTRATION (MIN)
1	690	0.03	4.617	4.617

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ROCK SIZING SPREADSHEETS

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 1 SLOPE SEGMENT # 1

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	550	FEET
AVE SLOPE:	0.044	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0169	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.01263	ACRES
Tc (actual):	3.345	MIN
% OF 1-HR PPT:	15.16	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	1.40	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0169	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.253	CFS
CONC. DISCHARGE:	0.253	CFS
DEPTH:	0.076	FEET
TRACTIVE FORCE:	0.209	PSF
FLOW VELOCITY:	3.316	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	2.52	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9990	
SIN(alpha):	0.0440	
x:	0.0427	
y:	0.8245	
D50:	0.045	FEET
	0.54	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 1 SLOPE SEGMENT # 2

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	965	FEET
AVE SLOPE:	0.034	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0166	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.02215	ACRES
Tc (actual):	6.320	MIN
% OF 1-HR PPT:	28.65	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	2.64	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0166	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.443	CFS
CONC. DISCHARGE:	0.443	CFS
DEPTH:	0.114	FEET
TRACTIVE FORCE:	0.242	PSF
FLOW VELOCITY:	3.885	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	1.95	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9994	
SIN(alpha):	0.0340	
x:	0.0494	
y:	0.8348	
D50:	0.051	FEET
	0.62	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 1 SLOPE SEGMENT # 3

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	1240	FEET
AVE SLOPE:	0.095	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0235	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.02847	ACRES
Tc (actual):	7.778	MIN
% OF 1-HR PPT:	35.26	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	3.24	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0235	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.570	CFS
CONC. DISCHARGE:	0.570	CFS
DEPTH:	0.120	FEET
TRACTIVE FORCE:	0.712	PSF
FLOW VELOCITY:	4.745	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR N0. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	5.43	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9955	
SIN(alpha):	0.0946	
x:	0.1452	
y:	0.7708	
D50:	0.164	FEET
	1.97	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 1 SLOPE SEGMENT # 4

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	1490	FEET
AVE SLOPE:	0.04	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0183	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.03421	ACRES
Tc (actual):	9.669	MIN
% OF 1-HR PPT:	43.83	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	4.03	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0183	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.685	CFS
CONC. DISCHARGE:	0.685	CFS
DEPTH:	0.150	FEET
TRACTIVE FORCE:	0.373	PSF
FLOW VELOCITY:	4.577	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	2.29	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9992	
SIN(alpha):	0.0400	
x:	0.0762	
y:	0.8286	
D50:	0.080	FEET
	0.96	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 1 SLOPE SEGMENT # 5

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	2040	FEET
AVE SLOPE:	0.022	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0158	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.04683	ACRES
Tc (actual):	14.038	MIN
% OF 1-HR PPT:	63.64	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	5.85	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0158	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.938	CFS
CONC. DISCHARGE:	0.938	CFS
DEPTH:	0.198	FEET
TRACTIVE FORCE:	0.272	PSF
FLOW VELOCITY:	4.737	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	1.26	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9998	
SIN(alpha):	0.0220	
x:	0.0554	
y:	0.8471	
D50:	0.057	FEET
	0.68	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 2 SLOPE SEGMENT # 1

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	275	FEET
AVE SLOPE:	0.051	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0165	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.00631	ACRES
Tc (actual):	1.853	MIN
% OF 1-HR PPT:	8.40	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	0.77	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0165	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.126	CFS
CONC. DISCHARGE:	0.126	CFS
DEPTH:	0.047	FEET
TRACTIVE FORCE:	0.151	PSF
FLOW VELOCITY:	2.665	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	2.92	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9987	
SIN(alpha):	0.0509	
x:	0.0308	
y:	0.8172	
D50:	0.033	FEET
	0.39	INCHES

E35

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 2 SLOPE SEGMENT # 2

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	1240	FEET
AVE SLOPE:	0.033	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0169	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.02847	ACRES
Tc (actual):	7.615	MIN
% OF 1-HR PPT:	34.52	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	3.18	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0169	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.570	CFS
CONC. DISCHARGE:	0.570	CFS
DEPTH:	0.135	FEET
TRACTIVE FORCE:	0.279	PSF
FLOW VELOCITY:	4.211	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	1.89	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9995	
SIN(alpha):	0.0330	
x:	0.0568	
y:	0.8358	
D50:	0.059	FEET
	0.71	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 2 SLOPE SEGMENT # 3

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	1450	FEET
AVE SLOPE:	0.048	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0193	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.03329	ACRES
Tc (actual):	9.157	MIN
% OF 1-HR PPT:	41.51	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	3.82	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0193	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.666	CFS
CONC. DISCHARGE:	0.666	CFS
DEPTH:	0.144	FEET
TRACTIVE FORCE:	0.431	PSF
FLOW VELOCITY:	4.632	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR N0. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	2.75	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9988	
SIN(alpha):	0.0479	
x:	0.0879	
y:	0.8203	
D50:	0.093	FEET
	1.12	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 2 SLOPE SEGMENT # 4

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	2970	FEET
AVE SLOPE:	0.012	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0247	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.06818	ACRES
Tc (actual):	21.224	MIN
% OF 1-HR PPT:	96.22	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	8.85	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0247	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	1.365	CFS
CONC. DISCHARGE:	1.365	CFS
DEPTH:	0.389	FEET
TRACTIVE FORCE:	0.291	PSF
FLOW VELOCITY:	3.511	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	0.69	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9999	
SIN(alpha):	0.0120	
x:	0.0594	
y:	0.8572	
D50:	0.060	FEET
	0.72	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 3 SLOPE SEGMENT # 1

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	140	FEET
AVE SLOPE:	0.05	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0153	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.00321	ACRES
Tc (actual):	1.110	MIN
% OF 1-HR PPT:	5.03	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	0.46	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0153	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.064	CFS
CONC. DISCHARGE:	0.064	CFS
DEPTH:	0.030	FEET
TRACTIVE FORCE:	0.095	PSF
FLOW VELOCITY:	2.116	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	2.86	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9988	
SIN(alpha):	0.0499	
x:	0.0194	
y:	0.8183	
D50:	0.021	FEET
	0.25	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 3 SLOPE SEGMENT # 2

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	280	FEET
AVE SLOPE:	0.029	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0139	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.00643	ACRES
Tc (actual):	2.480	MIN
% OF 1-HR PPT:	11.24	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	1.03	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0139	ANDERSON'S METHOD USED IF SLOPE < 2%
		CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.129	CFS
CONC. DISCHARGE:	0.129	CFS
DEPTH:	0.051	FEET
TRACTIVE FORCE:	0.093	PSF
FLOW VELOCITY:	2.511	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	1.66	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9996	
SIN(alpha):	0.0290	
x:	0.0189	
y:	0.8399	
D50:	0.020	FEET
	0.23	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 3 SLOPE SEGMENT # 3

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	1320	FEET
AVE SLOPE:	0.01	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0221	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.03030	ACRES
Tc (actual):	11.694	MIN
% OF 1-HR PPT:	53.01	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	4.88	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0221	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.607	CFS
CONC. DISCHARGE:	0.607	CFS
DEPTH:	0.236	FEET
TRACTIVE FORCE:	0.147	PSF
FLOW VELOCITY:	2.569	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	0.57	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	1.0000	
SIN(alpha):	0.0100	
x:	0.0301	
y:	0.8592	
D50:	0.030	FEET
	0.36	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 4 SLOPE SEGMENT # 1

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	275	FEET
AVE SLOPE:	0.011	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0188	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.00631	ACRES
Tc (actual):	3.345	MIN
% OF 1-HR PPT:	15.16	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	1.40	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0188	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.126	CFS
CONC. DISCHARGE:	0.126	CFS
DEPTH:	0.081	FEET
TRACTIVE FORCE:	0.056	PSF
FLOW VELOCITY:	1.555	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR N0. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	0.63	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9999	
SIN(alpha):	0.0110	
x:	0.0114	
y:	0.8582	
D50:	0.012	FEET
	0.14	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 4 SLOPE SEGMENT # 2

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	1520	FEET
AVE SLOPE:	0.008	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0218	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.03489	ACRES
Tc (actual):	15.443	MIN
% OF 1-HR PPT:	70.01	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	6.44	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0218	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.699	CFS
CONC. DISCHARGE:	0.699	CFS
DEPTH:	0.273	FEET
TRACTIVE FORCE:	0.136	PSF
FLOW VELOCITY:	2.563	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	0.46	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	1.0000	
SIN(alpha):	0.0080	
x:	0.0278	
y:	0.8613	
D50:	0.028	FEET
	0.34	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 5 SLOPE SEGMENT # 1

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	210	FEET
AVE SLOPE:	0.048	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0157	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.00482	ACRES
Tc (actual):	1.541	MIN
% OF 1-HR PPT:	6.99	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	0.64	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0157	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.097	CFS
CONC. DISCHARGE:	0.097	CFS
DEPTH:	0.040	FEET
TRACTIVE FORCE:	0.119	PSF
FLOW VELOCITY:	2.420	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR N0. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	2.75	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9988	
SIN(alpha):	0.0479	
x:	0.0244	
y:	0.8203	
D50:	0.026	FEET
	0.31	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 5 SLOPE SEGMENT # 2

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	935	FEET
AVE SLOPE:	0.014	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0222	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.02146	ACRES
Tc (actual):	7.973	MIN
% OF 1-HR PPT:	36.14	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	3.33	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0222	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.430	CFS
CONC. DISCHARGE:	0.430	CFS
DEPTH:	0.174	FEET
TRACTIVE FORCE:	0.152	PSF
FLOW VELOCITY:	2.469	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	0.80	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9999	
SIN(alpha):	0.0140	
x:	0.0310	
y:	0.8552	
D50:	0.032	FEET
	0.38	INCHES

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OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY   FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 5   SLOPE SEGMENT # 3

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS			CALCULATED PARAMETERS		
RUNOFF COEF:	0.8		DRAINAGE AREA:	0.03099	ACRES
SLOPE LENGTH:	1350	FEET	Tc (actual):	11.694	MIN
AVE SLOPE:	0.019	FT/FT	% OF 1-HR PPT:	53.01	(INTERPOLATED FROM TABLE 12.4)
RETURN PERIOD:	PMP	YRS	PPT AMOUNT:	4.88	INCHES
1-HR PPT AMOUNT:	9.2	INCHES	PPT INTENSITY:	25.02	INCHES/HOUR
FLOW CONC:	1		MANNING'S n:	0.0241	ANDERSON'S METHOD USED IF SLOPE < 2%
ASSUMED MANNING'S n:	0.0241				CSU METHOD USED IF SLOPE > 2%
			PEAK DISCHARGE:	0.620	CFS
			CONC. DISCHARGE:	0.620	CFS
			DEPTH:	0.208	FEET
			TRACTIVE FORCE:	0.247	PSF
			FLOW VELOCITY:	2.983	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:			CALCULATIONS:		
Spec. wt. of water:	62.4	pcf	TAN(phi):	0.8693	
Rock specific gravity:	2.65		COS(alpha):	0.9998	
Friction angle (phi):	41	degrees	SIN(alpha):	0.0190	
Slope angle (alpha):	1.09	degrees	x:	0.0503	
Safety factor:	1		y:	0.8501	
			D50:	0.051	FEET
				0.62	INCHES

OVERLAND FLOW AND RIPRAP CALCULATIONS USING THE SAFETY FACTORS METHOD

PROJECT: SMI 335 - JEFFREY CITY FILE: R\PROJECTS\335\QP\OVERFS.WQ1

LOCATION: PROFILE # 6 SLOPE SEGMENT # 1

OVERLAND FLOW CALCULATIONS (NUREG-4620, Methodologies for Evaluatiing Long-Term Stabilization Designs of Uranium Mill Tailings Impoundments)

INPUT PARAMETERS

RUNOFF COEF:	0.8	
SLOPE LENGTH:	690	FEET
AVE SLOPE:	0.03	FT/FT
RETURN PERIOD:	PMP	YRS
1-HR PPT AMOUNT:	9.2	INCHES
FLOW CONC:	1	
ASSUMED MANNING'S n:	0.0154	

CALCULATED PARAMETERS

DRAINAGE AREA:	0.01584	ACRES
Tc (actual):	4.617	MIN
% OF 1-HR PPT:	20.93	(INTERPOLATED FROM TABLE 12.4)
PPT AMOUNT:	1.93	INCHES
PPT INTENSITY:	25.02	INCHES/HOUR
MANNING'S n:	0.0154	ANDERSON'S METHOD USED IF SLOPE < 2% CSU METHOD USED IF SLOPE > 2%
PEAK DISCHARGE:	0.317	CFS
CONC. DISCHARGE:	0.317	CFS
DEPTH:	0.093	FEET
TRACTIVE FORCE:	0.173	PSF
FLOW VELOCITY:	3.422	FPS

TABLE 12.4 - From HMR-55A East of Continental Divide and West of 103 degree meridian
Percent of 1-hr local storm PMP for selected durations for 6- /1-hr ratio of 1.35 (HMR NO. 49)

RAINFALL DURATION (MIN)	PERCENT OF 1-HR PPT
0	0
15	68
30	86
45	94
60	100
120	116
180	123
240	128
300	132
360	135

RIPRAP SIZING CALCULATION (NUREG CR-4651, Development of Riprap design Criteria by Riprap Testing in Flumes: Phase I, Safety Factor Method)

INPUT PARAMETERS:

Spec. wt. of water:	62.4	pcf
Rock specific gravity:	2.65	
Friction angle (phi):	41	degrees
Slope angle (alpha):	1.72	degrees
Safety factor:	1	

CALCULATIONS:

TAN(phi):	0.8693	
COS(alpha):	0.9996	
SIN(alpha):	0.0300	
x:	0.0354	
y:	0.8389	
D50:	0.037	FEET
	0.44	INCHES

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CALCULATIONS FOR AREAS OUTSIDE THE DIVERSION DITCHES

PROJECT #336 | JEFFREY CITY | 10/06/93. C48 SBG

☐ HYDROLOGIC PARAMETERS FOR HEC1

- 1 HR. PMP = 9.20 INCHES.
- CURVE NUMBER = 89
- PRECIPITATION EVENT DISTRIBUTED USING SCS TYPE II DISTRIBUTION.
- 120 HYDROGRAPH ORDINATES TO BE COMPUTED AT 1.2 MIN. INTERVALS.

☐ DETERMINE SCS LAGTIME FOR 100' WIDE STRIP SHOWN IN FIG. 1.

$$t_p = \frac{l^{0.8}(S+1)^{0.7}}{1900Y^{0.5}}$$

WHERE;

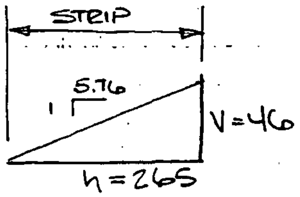
t_p = LAG TIME (HR.)

l = LENGTH TO DIVIDE

$S = (1000/CN) - 10$

Y = AVERAGE WATERSHED SLOPE (%)

CN = CURVE NUMBER



$l = (46^2 + 265^2)^{1/2} = 268.8'$

$Y = 0.17$ FT/FT.

$$S = (1000/89) - 10 = 1.24$$

$$t_p = \frac{(268.8)^{0.8}(1.24+1)^{0.7}}{1900(17.3)^{0.5}} = 0.0195$$

☐ DETERMINE AREA OF STRIP

AREA DETERMINED WITH ACAD 11 TO BE

0.6135 ACRES.

☐ RIPRAP SIZING FOR EMBANKMENT

- USE STEPHENSON'S METHOD FOR ROCK FILL ON STEEP SLOPES (10% OR GREATER)
  [REF NRC STP 90' PP D-2]

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

[REF: NUREG/CR-4651 PP 24]

D_{50} = MEDIAN ROCK SIZE, ft.

q = MAX UNIT DISCHARGE, cfs/ft (FROM HEC-1 RESULTS)

n_p = ROCK POROSITY
g = ACCELERATION DUE TO GRAVITY = 32.2 ft/s²
G_s = RELATIVE DENSITY of RIPRAP
θ = ANGLE OF SLOPE MEASURED FROM THE HORIZONTAL
ϕ = ANGLE of FRICTION of ROCK
C = EMPIRICAL FACTOR RANGING FROM 0.22 FOR GRAVEL to 0.27 FOR CRUSHED GRANITE.

FLOW CONCENTRATION FACTOR
REF: NUREG/CR-4651 VOL. 2 PP 77.

$$q = \frac{(24\,\text{cfs})(3.0)}{100'} = 0.72$$

n_p = 0.35 ; ASSUMED
G_s = 2.65
θ = 9.85°
ϕ = 41.5 [REF: GOLDMAN, S.J., et al, "EROSION & SEDIMENT CONTROL HANDBOOK" McGRAW HILL, N.Y., NY 1986]
C = 0.25 ; ASSUMED.

$$D_{50} = \left[\frac{0.72(\tan 9.85)^{7/6}\, 0.35^{1/6}}{0.25(32.2)^{1/2}\left[(1-0.35)(2.65-1)\cos 9.85(\tan 41.5 - \tan 9.85)\right]^{5/3}} \right]^{2/3}$$

$\approx 0.09' = \underline{1.1''}$

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```
*                                       *                                                   *                                    *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                                   *    U.S. ARMY CORPS OF ENGINEERS    *
*               MAY   1991              *                                                   *    HYDROLOGIC ENGINEERING CENTER   *
*            VERSION 4.0.1E             *                                                   *         609 SECOND STREET          *
*                                       *                                                   *      DAVIS, CALIFORNIA 95616       *
*  RUN DATE  10/25/93  TIME  08:14:14   *                                                   *           (916) 551-1748           *
*                                       *                                                   *                                    *
*****************************************                                                   **************************************




                                                X     X  XXXXXXX   XXXXX           X
                                                X     X  X        X     X         XX
                                                X     X  X        X                X
                                                XXXXXXX  XXXX     X        XXXXX   X
                                                X     X  X        X                X
                                                X     X  X        X     X          X
                                                X     X  XXXXXXX   XXXXX         XXX




          THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

          THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
          THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
          NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
          DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
          KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM
```

```
LINE            ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

   1            ID    INPUT FILE NAME:    R:\PROJECTS\336\HEC1\CANONIE.PMP\COVPRO.IH1
   2            ID    DATE: 09-27-93
   3            ID   EMBANKMENT COVER
   4            ID    JEFFREY CITY
                *DIAGRAM
   5            IT       1       0    0000     120       0       0
   6            IN       3       0       0
   7            IO       5       0
                *

   8            KK          RUNOFF FROM SUB-BASIN
   9            KO                                      21
  10            PB    9.20
  11            PC     .01     .02     .03     .04    .055     .07    .085    .105     .15    .205
  12            PC    .285    .425    .655    .765     .83     .88     .91     .93    .945     .96
  13            PC     .97     .98     .99     1.0
  14            BA  .00096
  15            LS       0      89
  16            UD   .0195
                *
  17            ZZ
```

```
                    SCHEMATIC DIAGRAM OF STREAM NETWORK
INPUT
 LINE      (V) ROUTING          (--->) DIVERSION OR PUMP FLOW

  NO.      (.) CONNECTOR        (<---) RETURN OF DIVERTED OR PUMPED FLOW

    8

(***) RUNOFF ALSO COMPUTED AT THIS LOCATION
```

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```
                                         RUNOFF SUMMARY
                                  FLOW IN CUBIC FEET PER SECOND
                                TIME IN HOURS,  AREA IN SQUARE MILES

                                  PEAK    TIME OF      AVERAGE FLOW FOR MAXIMUM PERIOD      BASIN    MAXIMUM    TIME OF
         OPERATION      STATION   FLOW     PEAK       6-HOUR      24-HOUR     72-HOUR       AREA     STAGE     MAX STAGE

         HYDROGRAPH AT              24.    0.60           2.          2.          2.       0.00


*** NORMAL END OF HEC-1 ***
```

APPENDIX F

CONFLUENCE EROSION PROTECTION

F1

APPENDIX F

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SECTION F.1

CONFLUENCE EROSION PROTECTION

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CONFLUENCE EROSION PROTECTION
WESTERN NUCLEAR, INC.

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CONFLUENCE EROSION PROTECTION
WESTERN NUCLEAR, INC.

PURPOSE. The purpose of these analyses is to determine the riprap sizes to prevent erosion during the 1000-year design life for the major drainages entering the diversion ditches.

METHOD. The design of the confluence modifications consisted of three steps:

1) surface hydrology,

2) open-ditch hydraulics, and

3) riprap design.

SURFACE HYDROLOGY. The Corps of Engineers HEC-1 model was used to calculate the run-off for the sub-basins shown in Figure F.1.1 (page F-14). The confluence basins were defined to estimate only the area that contributed to the flow through the confluences. Therefore, the basins delineated for the confluences are sub-basins of the larger basins delineated for the diversion ditch design. Based on the drainage basin characteristics and the precipitation distribution, the computer model determines peak flow of the entire basin. The HEC-1 output is attached.

The flood event used to evaluate the surface hydrology was the Probable Maximum Flood (PMF), which will result from the Probable Maximum Precipitation (PMP) of 9.2 inches for a 6-hour storm. This storm was selected according to the requirements of the NRC as set forth in the Final Staff Technical Position, Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailing Sites (NRC, 1990). The calculations for determination of the PMP value are given in Appendix B. The precipitation event was distributed for the HEC-1 analysis using the SCS Type II distribution (SCS, 1973) also discussed in Appendix B.

The SCS curve number method representing the antecedent moisture condition III (SCS, 1973) was used to estimate the precipitation runoff rate. Curve numbers for each sub-basin were calculated as described in Appendix B and provided in Table F.1.1 (page F-10).

The SCS dimensionless Unit Graph method (SCS, 1973) was used to generate the runoff hydrographs. This method requires the determination of the SCS Lag Time which is expressed as:

$$t_p = \frac{l^{0.8}(S+1)^{0.7}}{1900y^{0.5}}$$

where

t_p = lag time (hr.)
l = length to divide (ft.)
y = average watershed slope (%)
S = (1000/CN)-10
CN = curve number

The basin areas, curve numbers, hydraulic lengths, slopes, and lag times for the watersheds are provided in Table F.1.2 (page F-11).

OPEN-CHANNEL HYDRAULICS. As shown in Figure F.1.2 (page F-15), each confluence will be regraded such that the base of the confluence and bed of the diversion ditch are equal in elevation. This prevents the run-off's velocity from increasing as water flows down the original 3:1 diversion ditch side slope. A uniform bed slope at least 100 feet upstream from the diversion ditch will be provided so that uniform flow velocities and depths are achieved prior to the confluence. When the flow in the confluence reaches the uniform slope the flow will stabilize and conform to the ditch's normal depth and velocity.

The side slopes of the confluences will be regraded at a slope of 3:1 to allow riprap placement. At the intersection of the confluence side slopes and the diversion ditch side slopes, the surface will be rounded to improve the convergence of the two flows and to minimize erosion.
Using the peak discharges from the HEC-1 model, the hydraulic characteristics of the confluences were determined using normal depth as suggested by the NRC in the Final Staff Technical Position, Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailing Sites (NRC, 1990).

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Normal depth was calculated using an iterative solution of Manning's equation in conjunction with Darcy's equation (Chow 1959):

$$V = \frac{1.49}{n} R^{2/3} S^{1/2}$$

where V=mean velocity (ft/s)
R=hydraulic radius (ft)
S=slope of ditch bed (ft/ft)
n=Manning's coefficient

$$Q = V(A)$$

where Q=discharge (ft^3/s)
V=mean velocity (ft/s)
A=cross-sectional area (ft^2)

RIPRAP DESIGN. Stephenson and Safety Factors methods (Abt et.al, 1988) were used to determine the appropriate rock size required to prevent erosion due to confluence flow. For slopes greater than or equal to 10% the Stephenson Method was used, and for slopes less than 10% the Safety Factors Method was used. Both methods used the peak flows, calculated using HEC-1, to calculate the rock size necessary for the erosionally stability of the confluences. However, since the Safety Factors Method also requires the flow depth to compute the riprap size, the Normal depth iterative method, described above, was used to calculated the flow depth. The riprap calculation spreadsheets are attached.

In accordance with NRC guidance (NRC STP, 1990 pp. 18, 19 and D-29), the thickness of each riprap layer is based on the D_{50} of the riprap and is determined as:

riprap thickness = 6" when $D_{50} \leq 3"$
= 2 x D_{50} when $3 < D_{50} < 8"$
= 1.5 x D_{50} when $D_{50} \geq 8"$

RESULTS. The riprap sizes, as provided in Table F.1.3 (page F-12), will protect the diversion ditch against erosion at the major confluences.

The modified confluences will be lined with the appropriate riprap size to meet erosional stability. In each confluence the riprap will be placed along the side slopes allowing for 1-foot of freeboard. The flow depths of each confluence are also provided in Table F.1.3 (page F-12).

At the point of each confluence, riprap will also be placed as shown in Figure F.1.3 (page F-16). The riprap sized for the confluence will also be placed in the diversion ditch 50 feet upstream and downstream of the confluence. This will prevent erosion due to the additional turbulence caused by the convergence of the two flows. Beyond this distance the two flows will be converged, and ditch riprap as designed in Section C.1 of Appendix C will be sufficient to prevent erosion. Figure F.1.3 (page F-16) shows the riprap placement upstream and downstream of a typical confluence.

REFERENCES

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

U.S. Army Corps of Engineers (COE), Hydrologic Engineering Center, "Hydrograph Package, HEC-1," 1990.

U.S. Nuclear Regulatory Commission (NRC), "Final Staff Technical Position Design of Erosion Protection Covers for Stabilization of Uranium Mill Tailing Sites," 1990.

U.S. Soil Conservation Service (SCS), "A Method for estimating Volume and Rate of Runoff in Small Watersheds," Water Resource Publications, Littleton, CO., 1973.

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

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TABLES

F10

TABLE F.1.1
Proportions of Each Soil Type Within Each Drainage Area and Drainage Basin Weighted Curve Number

CONFLUENCE SUB-BASIN	TOTAL AREA ACRES	AREA GRANITE (CN=96)	AREA NATIVE SOIL (CN=67)	WEIGHTED CN
E (North 1)	18.26	13.97	4.29	89
H (South 1)	9.27	8.63	0.64	94
I (South 2)	18.00	16.34	1.66	93
J (South 3)	10.79	9.12	1.67	92
K (South 4)	20.52	19.39	1.13	94
O (North Central 1)	1.77	1.59	0.18	93

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TABLE F.1.2
Confluence Sub-Basin Characteristics

Confluence Sub-Basin	Area		Hydraulic Length (ft)	Surface Slope (%)	Curve Number	Lag Time (hr)
	(ft^2)	(mi^2)				
E	795,435	0.029	1715	15.3	89	0.091
H	403,979	0.014	1376	22.3	94	0.051
I	784,098	0.028	1322	19.3	93	0.056
J	469,994	0.017	1363	22.6	92	0.055
K	893,859	0.032	1952	15.0	94	0.082
O	77,052	0.003	485	25.5	93	0.022

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TABLE F.1.3
Riprap Sizes for Erosional Stability

CONFLUENCE	DISCHARGE (cfs)	DRAINAGE SLOPE (%)	FLOW DEPTH (ft)	RIPRAP D_{50} (in)
NORTH 1	495	9.2	0.66	12
SOUTH 1	300	6.25	0.61	8
SOUTH 2	584	7.0	1.20	16
SOUTH 3	354	11.3	0.77[A]	11
SOUTH 4	590	6.7	1.21	16
NORTH CENTRAL 1	76	33.2	0.25[A]	13

[A] Estimated using normal depth.

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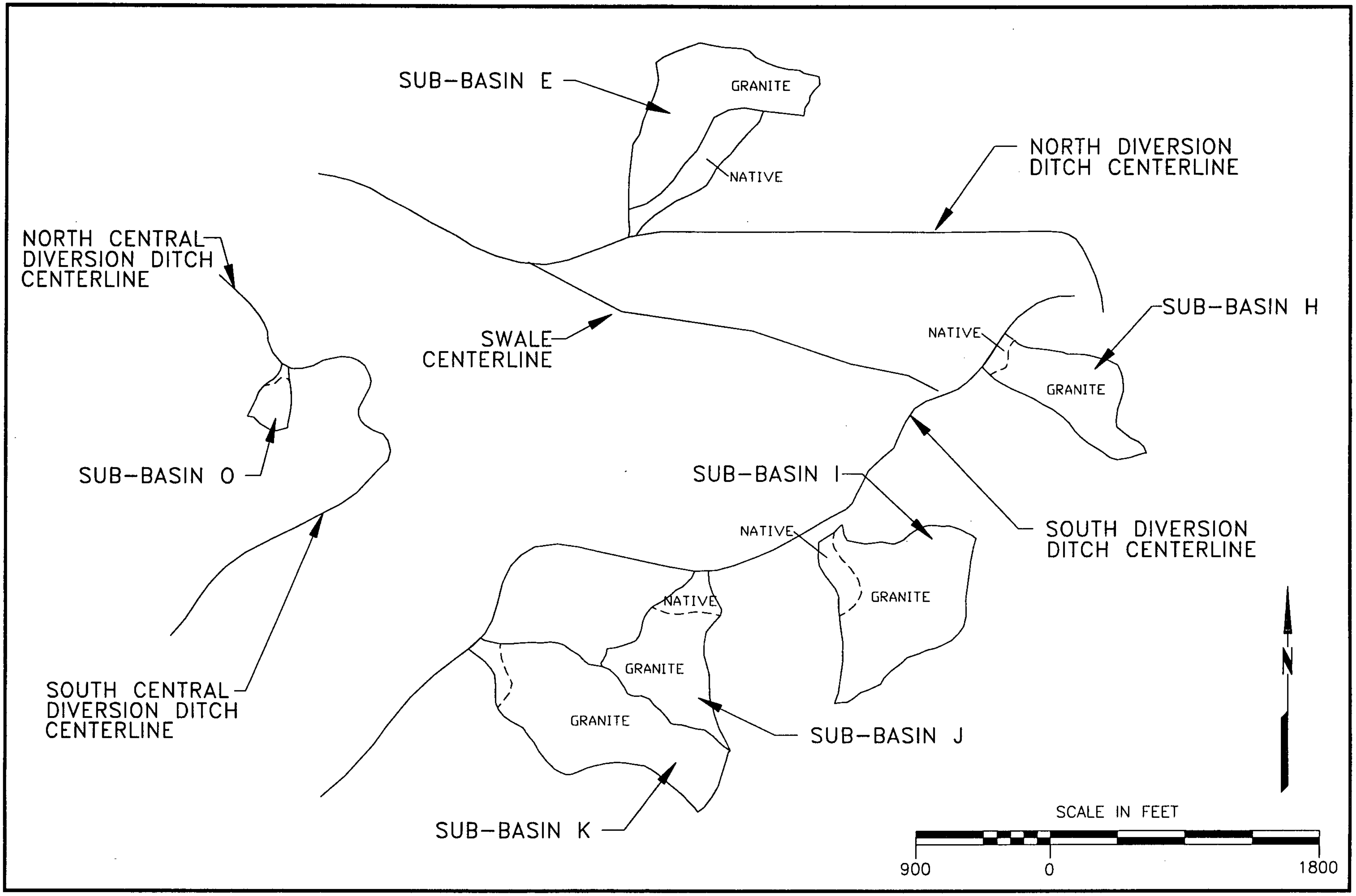
FIGURES

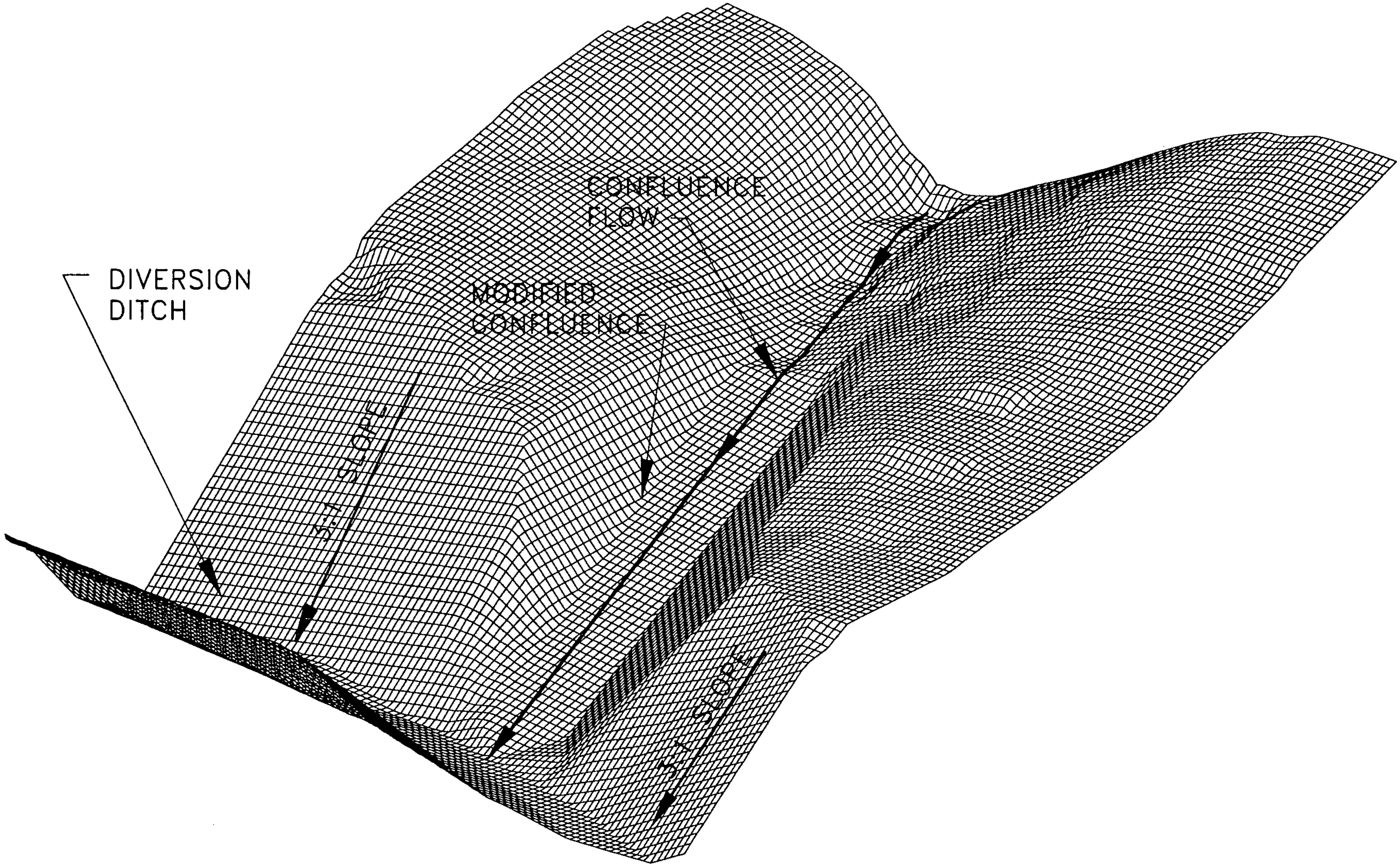


SMI
SHEPHERD MILLER, INC.

FIGURE F.1.1
CONFLUENCE SUB-BASINS

Date:	OCT., 1993
Project:	336
File:	SUB

F14



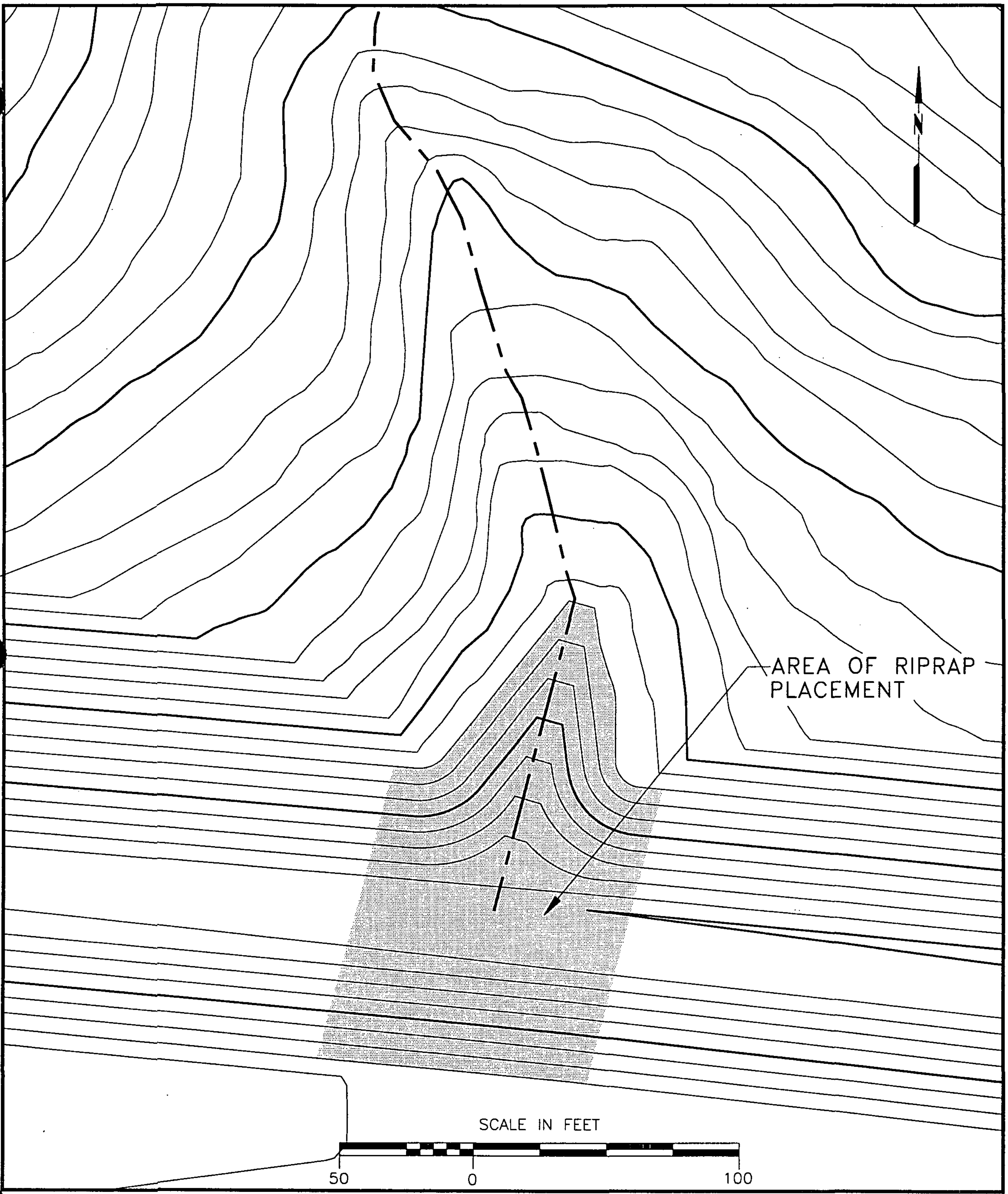
SMI
SHEPHERD MILLER, INC.

FIGURE F.1.2
TYPICAL CONFLUENCE DESIGN

Date:	OCT., 1993
Project:	336
File:	B-FGSLD

F15

F16



SMI
SHEPHERD MILLER, INC.

FIGURE F.1.3
TYPICAL CONFLUENCE
AND RIPRAP PLACEMENT

Date:	OCT., 1993
Project:	336
File:	TYPCONF

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SPREADSHEETS

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NORMAL DEPTH CALCULATION AND RIPRAP SIZING USING SAFETY FACTORS METHOD
REF: NUREG/CR-4651, pp. 18
FOR SLOPES LESS THAN 10%

File: R:\PROJECTS\336\QPRO\MANSF.WQ1
D[illegible]: 9-27-93

Location: North Ditch Confluence 1

Channel hydraulic properties using normal depth calculation

INPUT Flow (cfs):	495
INPUT Riprap D-50 (ft):	1
Manning's n:	0.0463
INPUT Bottom Width (ft):	100
INPUT Right Side Slope, z:	3
INPUT Left Side Slope, z:	3
INPUT Channel Slope (ft/ft):	0.092

QPro "Solve For" tool:

variable: formula:

Depth	F(y)
[illegible]6634	0.00

Depth (ft) =	0.663
Hydraulic Radius (ft) =	0.649
Cross-Sectional Area (sq ft) =	67.66
Average Velocity (fps) =	7.32
Topwidth (ft) =	103.98
Froude Number =	1.60
Flow Condition:	supercritical

RIP RAP CALULATION USINGS SAFETY FACTORS METHOD

INPUT Riprap Angle of Repose: 42
INPUT Rock Specific Gravity: 2.65

	RISE/RUN	RADS	DEGREES
Bed Slope:	0.092	0.092	5.26
Steepest Bank Slope:	0.3333333333333	0.322	18.43
Angle of Repose:		0.733	42.00

D-50 (ft)	DEPTH (ft)	T TRACTIVE FORCE	N STABILITY PARAMETER	B (RADS)	B DEGREES	N'	SAFETY FACTOR
0.25	0.66	3.81	3.11	1.26	72.31	3.07	0.30
0.5	0.66	3.81	1.55	1.07	61.36	1.49	0.57
0.75	0.66	3.81	1.04	0.91	52.29	0.95	0.81
1	0.66	3.81	0.78	0.79	45.00	0.69	1.01
1.25	0.66	3.81	0.62	0.68	39.18	0.53	1.19
1.5	0.66	3.81	0.52	0.60	34.52	0.42	1.33
1.75	0.66	3.81	0.44	0.54	30.74	0.35	1.45
2	0.66	3.81	0.39	0.48	27.66	0.30	1.55

NORMAL DEPTH CALCULATION AND RIPRAP SIZING USING SAFETY FACTORS METHOD
REF: NUREG/CR-4651, pp. 18
FOR SLOPES LESS THAN 10%

File: R:\PROJECTS\336\QPRO\MANSF.WQ1
D[illegible]: 9-27-93

Location: South Ditch Confluence 1

Channel hydraulic properties using normal depth calculation

====== ====== ======== =========
INPUT Flow (cfs): 300
INPUT Riprap D-50 (ft): 0.667
Manning's n: 0.0408
INPUT Bottom Width (ft): 75
INPUT Right Side Slope, z: 3
INPUT Left Side Slope, z: 3
INPUT Channel Slope (ft/ft): 0.0625
====== ====== ======== =========

QPro "Solve For" tool:

variable: formula:

Depth	F(y)
[illegible]6074	0.00

Depth (ft) = 0.607
Hydraulic Radius (ft) = 0.592
Cross-Sectional Area (sq ft) = 46.66
Average Velocity (fps) = 6.43
Topwidth (ft) = 78.64
Froude Number = 1.47
Flow Condition: supercritical

RIP RAP CALULATION USINGS SAFETY FACTORS METHOD

INPUT Riprap Angle of Repose: 42
INPUT Rock Specific Gravity: 2.65

	RISE/RUN	RADS	DEGREES
Bed Slope:	0.0625	0.062	3.58
Steepest Bank Slope:	0.3333333333333	0.322	18.43
Angle of Repose:		0.733	42.00

D-50 (ft)	DEPTH (ft)	T TRACTIVE FORCE	N STABILITY PARAMETER	B (RADS)	B DEGREES	N'	SAFETY FACTOR
0.25	0.61	2.37	1.93	1.17	66.89	1.88	0.47
0.5	0.61	2.37	0.97	0.90	51.66	0.88	0.86
→ $\boxed{0.667}$	0.61	2.37	0.72	0.77	44.04	0.63	1.08
0.75	0.61	2.37	0.64	0.71	40.89	0.55	1.17
1.25	0.61	2.37	0.39	0.49	27.97	0.29	1.57
1.5	0.61	2.37	0.32	0.42	23.99	0.24	1.70
1.75	0.61	2.37	0.28	0.37	20.95	0.20	1.81
2	0.61	2.37	0.24	0.32	18.58	0.17	1.90

rdu

NORMAL DEPTH CALCULATION AND RIPRAP SIZING USING SAFETY FACTORS METHOD

REF: NUREG/CR-4651, pp. 18

FOR SLOPES LESS THAN 10%

File: R:\PROJECTS\336\QPRO\MANSF.WQ1

Date: 9-27-93

Location: South Ditch Confluence 2

Channel hydraulic properties using normal depth calculation

INPUT Flow (cfs):	584
INPUT Riprap D-50 (ft):	1.33
Manning's n:	0.0464
INPUT Bottom Width (ft):	50
INPUT Right Side Slope, z:	3
INPUT Left Side Slope, z:	3
INPUT Channel Slope (ft/ft):	0.07

QPro "Solve For" tool:

variable: formula:

Depth	F(y)
[illegible]1951	-0.00

Depth (ft) =		1.195
Hydraulic Radius (ft) =		1.113
Cross-Sectional Area (sq ft) =		64.04
Average Velocity (fps) =		9.12
Topwidth (ft) =		57.17
Froude Number =		1.52
Flow Condition:	supercritical	

RIP RAP CALULATION USINGS SAFETY FACTORS METHOD

INPUT Riprap Angle of Repose:	42
INPUT Rock Specific Gravity:	2.65

	RISE/RUN	RADS	DEGREES
Bed Slope:	0.07	0.070	4.00
Steepest Bank Slope:	0.3333333333333	0.322	18.43
Angle of Repose:		0.733	42.00

D-50 (ft)	DEPTH (ft)	T TRACTIVE FORCE	N STABILITY PARAMETER	B (RADS)	B DEGREES	N'	SAFETY FACTOR
0.25	1.20	5.22	4.26	1.34	76.76	4.23	0.22
0.5	1.20	5.22	2.13	1.19	68.17	2.08	0.43
0.667	1.20	5.22	1.60	1.10	62.93	1.53	0.56
0.75	1.20	5.22	1.42	1.06	60.49	1.35	0.62
1.25	1.20	5.22	0.85	0.84	48.12	0.76	0.95
→ $\boxed{1.33}$	1.20	5.22	0.80	0.81	46.48	0.71	1.00
1.5	1.20	5.22	0.71	0.76	43.28	0.62	1.09
1.75	1.20	5.22	0.61	0.68	39.17	0.51	1.21

STEPHENSON'S METHOD FOR SIZING RIPRAP
REF: NUREG/CR-4651 pp.22, PHASE II, ABT ET AL.
FOR SLOPES GREATER THAN OR EQUAL TO 10%

FILE: R:\PROJECTS\336\QPRO\STEPH2.WQ1
DATE: 09\27\93

LOCATION: SOUTH DITCH CONFLUENCE 3

FLOW RATE PER UNIT WIDTH = 7.08 CFS/FT
ROCKFILL POROSITY = 0.35
SPECIFIC GRAVITY = 2.65
SLOPE OF EMBANKMENT = 11.3 PERCENT
FRICTION ANGLE = 42 DEGREES
EMPIRICAL FACTOR = 0.25
OLIVIERS' CONSTANT = 1.8

MEDIAN STONE SIZE D50 = 0.86 FT $\boxed{10.3 \text{ IN}}$

NORMAL DEPTH CALCULATION AND RIPRAP SIZING USING SAFETY FACTORS METHOD

REF: NUREG/CR-4651, pp. 18
FOR SLOPES LESS THAN 10%

File: R:\PROJECTS\336\QPRO\MANSF.WQ1
Date: 9-27-93

Location: South Ditch Confluence 4

Channel hydraulic properties using normal depth calculation

INPUT Flow (cfs):	590
INPUT Riprap D-50 (ft):	1.33
Manning's n:	0.0461
INPUT Bottom Width (ft):	50
INPUT Right Side Slope, z:	3
INPUT Left Side Slope, z:	3
INPUT Channel Slope (ft/ft):	0.067

QPro "Solve For" tool:

variable: formula:

Depth	F(y)
1.2129	0.00

Depth (ft) = 1.213
Hydraulic Radius (ft) = 1.128
Cross-Sectional Area (sq ft) = 65.06
Average Velocity (fps) = 9.07
Topwidth (ft) = 57.28
Froude Number = 1.50
Flow Condition: supercritical

RIP RAP CALULATION USINGS SAFETY FACTORS METHOD

INPUT Riprap Angle of Repose:	42
INPUT Rock Specific Gravity:	2.65

	RISE/RUN	RADS	DEGREES
Bed Slope:	0.067	0.067	3.83
Steepest Bank Slope:	0.3333333333333	0.322	18.43
Angle of Repose:		0.733	42.00

D-50 (ft)	DEPTH (ft)	T TRACTIVE FORCE	N STABILITY PARAMETER	B (RADS)	B DEGREES	N'	SAFETY FACTOR
0.25	1.21	5.07	4.14	1.34	76.66	4.11	0.23
0.5	1.21	5.07	2.07	1.18	67.84	2.02	0.44
0.667	1.21	5.07	1.55	1.09	62.48	1.49	0.58
0.75	1.21	5.07	1.38	1.05	59.99	1.31	0.64
1.25	1.21	5.07	0.83	0.83	47.45	0.74	0.97
→ 1.33	1.21	5.07	0.78	0.80	45.81	0.69	1.02
1.5	1.21	5.07	0.69	0.74	42.59	0.59	1.11
1.75	1.21	5.07	0.59	0.67	38.48	0.49	1.23

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STEPHENSON'S METHOD FOR SIZING RIPRAP
REF: NUREG/CR-4651 pp.22, PHASE II, ABT ET AL.
FOR SLOPES GREATER THAN OR EQUAL TO 10%

FILE: R:\PROJECTS\336\QPRO\STEPH2.WQ1
DATE: 09\27\93

LOCATION: NORTH CENTRAL DITCH CONFLUENCE 1

FLOW RATE PER UNIT WIDTH = 1.52 CFS/FT
ROCKFILL POROSITY = 0.35
SPECIFIC GRAVITY = 2.65
SLOPE OF EMBANKMENT = 33.2 PERCENT
FRICTION ANGLE = 42 DEGREES
EMPIRICAL FACTOR = 0.25
OLIVIERS' CONSTANT = 1.8

MEDIAN STONE SIZE D50 = 1.07 FT $\boxed{\text{12.9 IN}}$

F24

HEC-1 OUTPUT

F25

```
*****************************************                                   ***************************************
*                                       *                                   *                                     *
*   FLOOD HYDROGRAPH PACKAGE  (HEC-1)   *                                   *   U.S. ARMY CORPS OF ENGINEERS      *
*              MAY   1991               *                                   *   HYDROLOGIC ENGINEERING CENTER     *
*           VERSION 4.0.1E              *                                   *         609 SECOND STREET           *
*                                       *                                   *      DAVIS, CALIFORNIA 95616        *
*  RUN DATE  09/28/93  TIME  10:56:24   *                                   *          (916) 551-1748             *
*                                       *                                   *                                     *
*****************************************                                   ***************************************




                                               X     X  XXXXXXX   XXXXX           X
                                               X     X  X        X     X         XX
                                               X     X  X        X                X
                                               XXXXXXX  XXXX     X        XXXXX   X
                                               X     X  X        X                X
                                               X     X  X        X     X          X
                                               X     X  XXXXXXX   XXXXX          XXX
```

SUB-BASINS FOR CONFLUENCE DESIGN

```
            THIS PROGRAM REPLACES ALL PREVIOUS VERSIONS OF HEC-1 KNOWN AS HEC1 (JAN 73), HEC1GS, HEC1DB, AND HEC1KW.

            THE DEFINITIONS OF VARIABLES -RTIMP- AND -RTIOR- HAVE CHANGED FROM THOSE USED WITH THE 1973-STYLE INPUT STRUCTURE.
            THE DEFINITION OF -AMSKK- ON RM-CARD WAS CHANGED WITH REVISIONS DATED 28 SEP 81. THIS IS THE FORTRAN77 VERSION
            NEW OPTIONS: DAMBREAK OUTFLOW SUBMERGENCE , SINGLE EVENT DAMAGE CALCULATION, DSS:WRITE STAGE FREQUENCY,
            DSS:READ TIME SERIES AT DESIRED CALCULATION INTERVAL   LOSS RATE:GREEN AND AMPT INFILTRATION
            KINEMATIC WAVE: NEW FINITE DIFFERENCE ALGORITHM
```

```
LINE           ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10

   1           ID    INPUT FILE NAME:    R:\PROJECTS\336\HEC1\CANONIE.PMP\CONS.IH1
   2           ID    DATE: 09-27-93
   3           ID    CONFLUENCES
   4           ID    JEFFREY CITY
               *DIAGRAM
   5           IT       1       0    0000     120       0       0
   6           IN       3       0       0
   7           IO       5       0
               *

   8           KK     SBE  RUNOFF FROM SUB-BASIN E
   9           KO                                      21
  10           PB    9.20
  11           PC     .01     .02     .03     .04    .055     .07    .085    .105     .15    .205
  12           PC    .285    .425    .655    .765     .83     .88     .91     .93    .945     .96
  13           PC     .97     .98     .99     1.0
  14           BA    .029
  15           LS       0      89
  16           UD    .091
               *

  17           KK      N1  RUNOFF FROM SUB-BASIN E INTO NORTH CONFLUENCE 1
  18           KO                                      21
  19           BA    .029
  20           LS       0      89
  21           UD    .091
               *

  22           KK      S1  RUNOFF FROM SUB-BASIN H INTO SOUTH CONFLUENCE 1
  23           KO                                      21
  24           BA    .014
  25           LS       0      94
  26           UD    .051
               *

  27           KK      S2  RUNOFF FROM SUB-BASIN I INTO SOUTH CONFLUENCE 2
  28           KO                                      21
  29           BA    .028
  30           LS       0      93
  31           UD    .056
               *

  32           KK      S3  RUNOFF FROM SUB-BASIN J INTO SOUTH CONFLUENCE 3
  33           KO                                      21
  34           BA    .017
  35           LS       0      92
  36           UD    .055
               *

  37           KK      S4  RUNOFF FROM SUB-BASIN K INTO SOUTH CONFLUENCE 4
  38           KO                                      21
  39           BA    .032
  40           LS       0      94
  41           UD    .082
               *
```

```
LINE          ID.......1.......2.......3.......4.......5.......6.......7.......8.......9......10


  42          KK     NC1  RUNOFF FROM SUB-BASIN O INTO NORTH CENTRAL CONFLUENCE 1
  43          KO                                      21
  44          BA    .003
  45          LS       0       93
  46          UD    .022
              *
  47          ZZ
```

```
                SCHEMATIC DIAGRAM OF STREAM NETWORK
INPUT
 LINE      (V) ROUTING          (--->) DIVERSION OR PUMP FLOW

  NO.      (.) CONNECTOR        (<---) RETURN OF DIVERTED OR PUMPED FLOW

    8         SBE
                .
                .
   17           .          N1
                .           .
                .           .
   22           .           .          S1
                .           .           .
                .           .           .
   27           .           .           .          S2
                .           .           .           .
                .           .           .           .
   32           .           .           .           .          S3
                .           .           .           .           .
                .           .           .           .           .
   37           .           .           .           .           .          S4
                .           .           .           .           .           .
                .           .           .           .           .           .
   42           .           .           .           .           .           .         NC1

(***) RUNOFF ALSO COMPUTED AT THIS LOCATION
```

```
                                    RUNOFF SUMMARY
                               FLOW IN CUBIC FEET PER SECOND
                            TIME IN HOURS,  AREA IN SQUARE MILES

                                  PEAK    TIME OF     AVERAGE FLOW FOR MAXIMUM PERIOD      BASIN    MAXIMUM    TIME OF
   OPERATION        STATION       FLOW     PEAK        6-HOUR      24-HOUR      72-HOUR     AREA     STAGE    MAX STAGE

   HYDROGRAPH AT        SBE       495.     0.67          74.          74.          74.     0.03

   HYDROGRAPH AT         N1       495.     0.67          74.          74.          74.     0.03  NORTH CONFLUENCE 1

   HYDROGRAPH AT         S1       300.     0.63          39.          39.          39.     0.01  SOUTH CONFLUENCE 1

   HYDROGRAPH AT         S2       584.     0.63          76.          76.          76.     0.03  SOUTH CONFLUENCE 2

   HYDROGRAPH AT         S3       354.     0.63          46.          46.          46.     0.02  SOUTH CONFLUENCE 3

   HYDROGRAPH AT         S4       590.     0.67          88.          88.          88.     0.03  SOUTH CONFLUENCE 4

   HYDROGRAPH AT        NC1        76.     0.60           8.           8.           8.     0.00  NORTH CENTRAL
                                                                                                CONFLUENCE 1

*** NORMAL END OF HEC-1 ***
```

APPENDIX G
RADON BARRIER COVER DESIGN

APPENDIX G

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SECTION G.1

RADON BARRIER COVER DESIGN

RADON BARRIER COVER DESIGN
WESTERN NUCLEAR, INC.

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RADON BARRIER COVER DESIGN
WESTERN NUCLEAR,INC.

PURPOSE. The purpose of these calculations is to determine an acceptable final reclamation cover system with an appropriate radon barrier layer thickness to attenuate the release of Radon-222 from uranium by-product materials so as not to exceed an average release rate of 20 pCi/m^2/sec. These calculations either meet or exceed the requirements stipulated in Criterion 6, Appendix A, of 10 CFR 40 for the design of an earthen cover placed over tailing at the end of milling operations.

The final reclamation cover is comprised of an imported clay (Cody Shale) layer. A 12-inch thick borrow soil layer is placed over the imported clay layer. Radon attenuation properties of the interim borrow soil layer between the tailing and the imported clay layer, of the borrow soil layer overlying the imported clay layer, and of the soil/rock matrix overlying the borrow soil layer are not accounted for in the model. These layers will provide additional radon attenuation thus introducing additional conservatism into the radon barrier design.

METHOD. The radon barrier was designed using the NRC Radon Model (NRC. 1989). The model was run following the guidelines presented in:

> "Radon Attenuation Handbook for Uranium Mill Tailings Cover Design, " NRC NUREG/CR-3533, 1984 (NRC, 1984).
>
> "Calculation of Radon Flux Attenuation by Earthen Uranium Mill Tailings Covers," NRC Regulatory Guide 3.64, 1989 (NRC, 1989).

ASSUMPTIONS.

Compacted Densities of Radon Barrier.

The general cover design includes the first six-inch lift of Cody Shale placed over tailing at 90% of standard Proctor, followed by a layer of Cody Shale placed in six inch lifts at a minimum of 95% of standard Proctor, followed by a one-foot protective sand layer, followed by a six-inch rock mulch layer for erosional stability. The final reclamation cover design and corresponding erosion protection are presented in Figure G.1.1 (page G-18). The thickness of the Cody Shale layer placed at 95% standard Proctor was determined and optimized by the RADON model.

The protective sand layer will be not be mechanically compacted when placed, nor will it be field tested for placement density. Therefore, the default density and porosity were used for this layer in the NRC RADON model.

No credit was taken for attenuation capabilities of the soil/rock mulch layer.

Radiological Source Terms.

The Split Rock Mill has been separated into eight different areas. These areas are delineated on Figure G.1.2 (page G-19) and designated as follows:

Area 1A - East new tailing
Area 1B - West new tailing
Area 1C - Old tailing
Area 2A - Alternate tailing area
Area 2B - Old tailing
Area 2C - Winter storage pond area
Area 3A - Mill area with tailing
Area 3B - Mill area without tailing

The low-level radioactive waste burial area was covered with varying amounts of coarse tailing and uncontaminated soils in 1990 and has been included in Area 2B.

The mill area without imported tailing (Area 3B) has a limited amount of radium-226 contamination primarily due to windblown tailing. This area did not receive tailing during the 1990 regrading activities. The mill area with tailing (Area 3A) received tailing during regrading activities conducted in 1990.

As agreed by WNI and the NRC, a radium activity of 1.1 pCi/g was assumed for the borrow soil layer, the protective sand cover overlying the radon barrier layer. This is to account for the possible presence of affected soils in the sandy soil borrow areas.

For areas where the diversion ditches are constructed through tailing, the radiological parameters, and thus the cover design, are identical to those used for tailing in the same area regardless of the thickness of tailing (i.e. an infinite thickness of tailing is assumed).

Each area has different input parameters for the RADON model and consequently, each area requires a different cover thickness. Methodologies for determining each RADON model input parameter are described below and all calculations are presented in Attachment B.

The only data used in these calculations is from the upper fifteen feet of any given tailing area. Regrading activities were taken into consideration when using data collected prior to the regrading. Particularly, the top 9 feet of WWL boring 1, the top 19 feet of WWL boring 2, the top 12 feet of WWL boring 3, and the top 9 feet of WWL boring 4 were moved from the west new tailing area (Area 1B) to the east new tailing area (Area 1A).

Groundwater Corrective Action Program - Winter Storage Ponds.

The final cover thickness for the winter storage ponds area cannot be determined until the ponds are dismantled and a source term can be obtained. It is assumed that the winter storage ponds will be reclaimed in place and it is expected that the source term for the reclaimed ponds will be small since there appears to be only approximately a one inch thick sludge in the pond bottoms. Therefore, for the purposes of this brief, a minimal six inch cover of cody shale placed at 90% of standard Proctor has been assumed. The final cover thickness will be determined at the time of reclamation of these ponds. The reclamation design has provided for backfilling of the ponds and recontouring of the berms to bring the subgrade to accommodate the final reclamation cover and result in a final surface configuration as shown on Figure 5 of 10 of the Reclamation Plan Drawings.

Radon Barrier Layer.

The performance of a radon barrier is dependent on the following parameters:

1. thickness of tailing
2. thickness of cover layers
3. porosity of cover and tailing materials
4. moisture content of cover and tailing materials
5. dry density of cover and tailing materials
6. specific gravity of cover and tailing materials
7. emanation coefficient of the tailing
8. radium activity of the tailing

The NRC Radon model provides default values for specific gravity of cover materials and tailing, moisture content of tailing, emanation coefficient, and dry density of tailing. Default values are recommended unless documented parameters are available.

For the design of the cover system in this report, the default porosity of 0.4 was used for the mill area without imported tailing (Area 3B) and for the west new tailing area

(Area 1B). All other (radiological source term) tailing parameters, with the exception of the radon diffusion coefficients (calculated by the model), were obtained from the following:

- sampling activities conducted by Shepherd Miller in January, 1993;

- data presented in Appendix A of the Canonie Environmental report entitled "Western Nuclear, Inc. Split Rock Mill, March 1992 - Response to NRC Comments on the Uranium Tailings Reclamation Plan" including data collected by Water, Waste and Land (WWL) in 1988;

- and data collected by Radiant Energy Management (REM) in 1987 (submitted in 1988 as Revision No. 1 to the June 1987 WNI Tailing Reclamation Plan).

Table G.1.1 (page G-14) and Table G.1.2 (page G-15) summarize the radiological source term parameters used in the NRC RADON Model for the design of the Split Rock Mill cover system. Justification for the use of these parameters is provided below, and laboratory analysis results and calculations are presented in Attachment B. Radon Model output is presented in Attachment A.

Summary of Cody Shale Composite Values Assumed in the NRC RADON Model.

To determine an appropriate cover material, four deep Cody Shale composite samples, created from samples collected by SMI in December, 1992, were tested for geotechnical properties related to radon attenuation. These Composites, Numbered One through Four, had percent fine contents of 90 or less, 90 - 92, 92 - 95, and 95 - 98, respectively. Table 2 presents the parameters used in the RADON model for the Cody Shale.

Material represented by Composite Number One was found only in the surficial material in one area. This surficial material will not be used for the cover. The remainder of the cody shale is represented by Composites Number Two, Three, and Four. The values for Composite Two were used in the RADON model as they give the thickest cover requirement.

Construction specifications will ensure that all material used in the cover will meet or exceed the radon attenuation characteristics assumed in the model.

Borrow Soil Layer.

No credit has been taken for the radon attenuation characteristics of the borrow soil layer overlying the radon barrier layer. The borrow soil layer is assumed, however, to consist entirely of affected soils containing an average radium-226 activity of 1.1 pCi/g. Default values are used for the required geotechnical parameters such as porosity and dry density. The use of default values will therefore require no extraordinary compactive requirements other than the compaction achieved by local traffic for placement of the borrow soil layer.

INPUT PARAMETERS FOR THE RADON MODEL.

Moisture Content.

Laboratory 15-bar moisture contents were used for the tailing long-term moisture content in all areas.

The moisture content for the Cody Shale radon barrier layer is the 15-bar value determined in the laboratory. The 15-bar moisture content represents essentially the residual moisture content of the soil.

A 2% moisture content was assumed for the borrow soil layer overlying the radon barrier. This is a typical value for sandy material and is less than the default value of 6%.

Specific Gravity.

The default specific gravity of 2.65 was used for the borrow soil layer and the tailing in the east new tailing area (Area 1A).

Laboratory values were used for the Cody Shale and for composite tailing samples representing the tailing from all other tailing areas.

Dry Density.

Dry densities used in the model for the radon barrier layer are 90% of standard proctor density for the lower six inches and 95% of standard Proctor for the remainder of the Cody Shale.

Dry densities for the various tailing are the averages of available in-situ densities from field sampling events.

No in-situ density was available for the borrow soil layer, the west new tailing area (Area 1B), and the mill area without tailing (Area 3B). In these areas, a dry density was calculated using the specific gravity and the default porosity of 0.4.

Porosity.

Porosity is calculated using the formula:

$$\eta = 1 - \frac{\rho_d}{G_s \times \rho_w}$$

Where:
η = porosity
ρ_d = dry density
G_s = specific gravity
ρ_w = density of water

The default porosity of 0.4 was used for the borrow soil layer, the mill area without tailing (Area 3B), and the west new tailing area (Area 1B) due to the lack of in-situ density data.

Radium Activity & Emanation Coefficient.

An average radium activity determined from the tailing samples located in the top 15-feet of tailing was used in the RADON Model. The tailings radium activities are presented in Attachment B.

The default emanation coefficient was used for the mill area without tailing (Area 3B) because no laboratory data were available for this area. For all other areas, laboratory data were available for this parameter.

A radium activity of 1.1 pCi/g and the default emanation coefficient of 0.35 were used for the borrow soil layer.

Diffusion Coefficients.

Radon diffusion coefficients were calculated by the NRC RADON model.

Layer Thicknesses.

For all areas, a minimum default tailing thickness of 500 cm was used in the RADON model.

The first layer of Cody Shale (90% Proctor) is six inches.

The thickness of the remaining Cody Shale radon barrier layer was optimized by the NRC RADON program.

The borrow soil layer is one foot thick.

SUMMARY. The radon barrier thickness for each area is presented in Table G.1.3 (page G-16). Radon flux from the radon barrier is limited to slightly less than 20 $pCi/m^2/s$ to account for the assumed presence of affected soils containing an average radium-226 activity of 1.1 pCi/g in the borrow soil layer overlying the radon barrier layer.

A minimum cover of 6 inches will be placed in the mill area without tailing (Area 3B). Since the cover thickness for the winter storage ponds cannot be determined until a source term can be obtained, a design thickness of six inches is assumed herein. This will allow for a radium-226 activity of approximately 27 pCi/g in the pond area assuming an emanation coefficient of 0.35 and default porosity and moisture content for the soils in this area.

REFERENCES.

U.S. Nuclear Regulatory Commission, (NRC), "Radon Attenuation Handbook for Uranium Mill Tailings Cover Design," NUREG/CR-3533, 1984.

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

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Tables

Table G.1.1
Radiological Source Term Parameters Used in the RADON Model

AREA	SPECIFIC GRAVITY	DRY UNIT WEIGHT (g/cm^3)	POROSITY	WATER CONTENT	EMANATION COEFFICIENT	RADIUM CONTENT (pCi/g)
AREA 1A - EAST NEW TAILING	2.65^D	1.62	.39^C	1.5%	.28	280
AREA 1B - WEST NEW TAILING	2.59	1.55^C	.40^D	1.5%	.37	450
AREA 1C - OLD TAILING	2.65	1.61	.39^C	3.58%	.25	341
AREA 2A - ALTERNATE TAILING	2.62	1.64	.36^C	2.15%	.25	448
AREA 2B - OLD TAILING	2.65	1.61	.39^C	3.58%	.25	341
AREA 2C - WINTER STORAGE PONDS	N/A	N/A	N/A	N/A	N/A	N/A
AREA 3A - MILL AREA WITH TAILING	2.62	1.65	.37^C	2.15%	.17	88.0
AREA 3B - MILL AREA W/O TAILING TOP 1 FOOT LOWER 14 FEET	2.61 2.61	1.57^C 1.57^C	.40^D .40^D	1.5% 1.5%	.35^D .35^D	20.3 5.5

D = DEFAULT VALUE
C = CALCULATED BY $\rho = G_s(1-\eta)$ OR $\eta = 1 - \rho/G_s$
N/A = Not applicable, source terms will not be determined until final reclamation of the storage ponds.

Table G.1.2
Cover Material Parameters Used in the RADON Model

COVER MATERIAL	SPECIFIC GRAVITY	DRY UNIT WEIGHT (g/cm^3)	POROSITY	WATER CONTENT	RADIUM ACTIVITY	EMANATION COEFFICIENT
CODY SHALE @ 90% PROCTOR	2.78	1.59	0.44^C	16.9%	0	N/A
CODY SHALE @ 95% PROCTOR	2.78	1.65	0.41^C	16.9%	0	N/A
BORROW SOIL LAYER	2.65^D	1.55^C	0.40^D	2.0%	1.1 pCi/g	0.35^D

D = DEFAULT VALUE
C = CALCULATED BY $\rho = G_s(1-\eta)$ OR $\eta = 1 - \rho/G_s$

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Table G.1.3
Radon Barrier Thickness

AREA	REQUIRED MINIMUM COVER THICKNESS IN INCHES	DESIGN COVER THICKNESS IN INCHES
AREA 1A - EAST NEW TAILING	32.1	33
AREA 1B - WEST NEW TAILING	43.7	44
AREA 1C - OLD TAILING	33.9	34
AREA 2A - ALTERNATE TAILING	39.6	40
AREA 2B - OLD TAILING	33.9	34
AREA 2C - WINTER STORAGE PONDS	N/A	6
AREA 3A - MILL AREA WITH TAILING	10.4	11
AREA 3B - MILL AREA W/O TAILING	0	6

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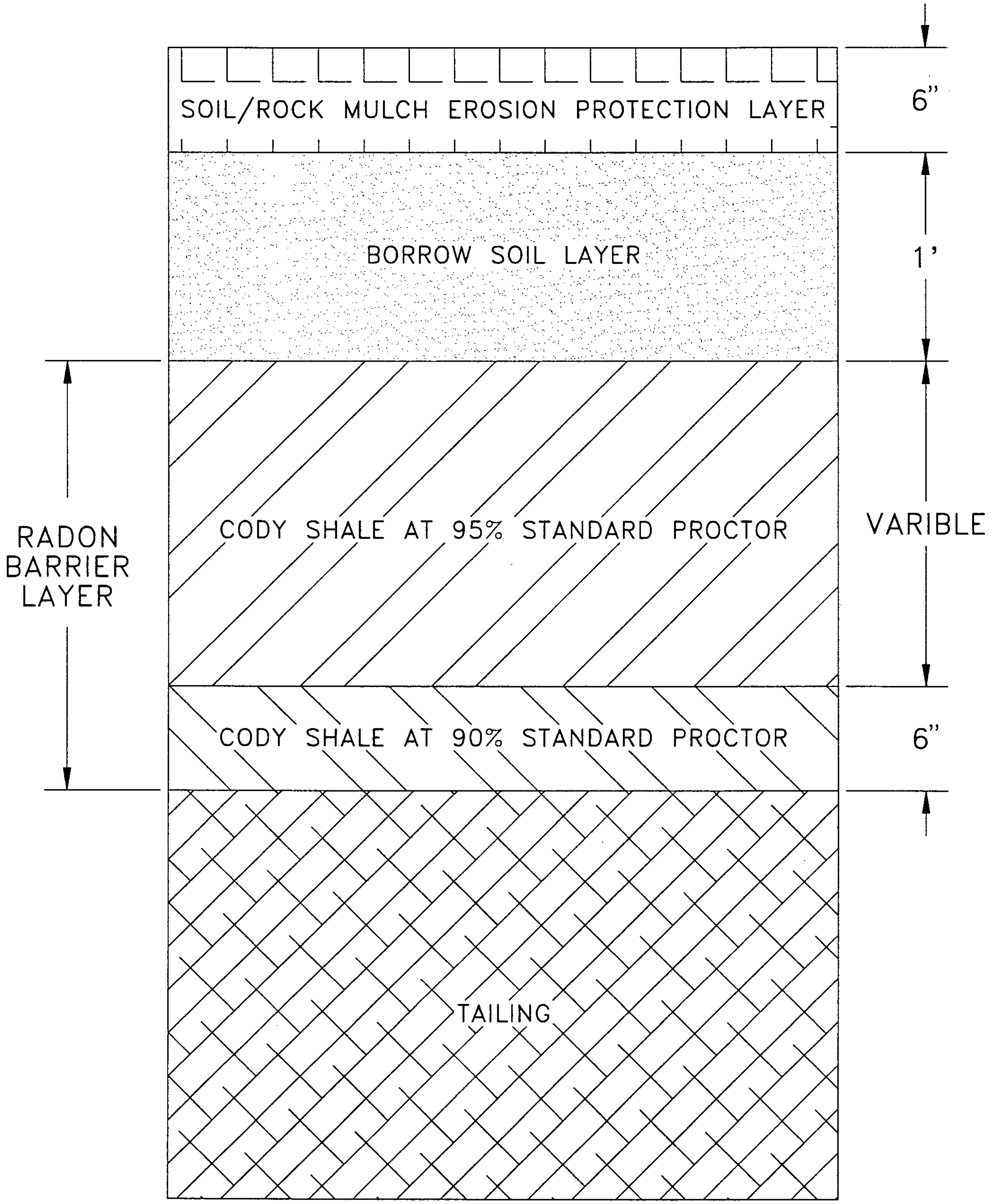
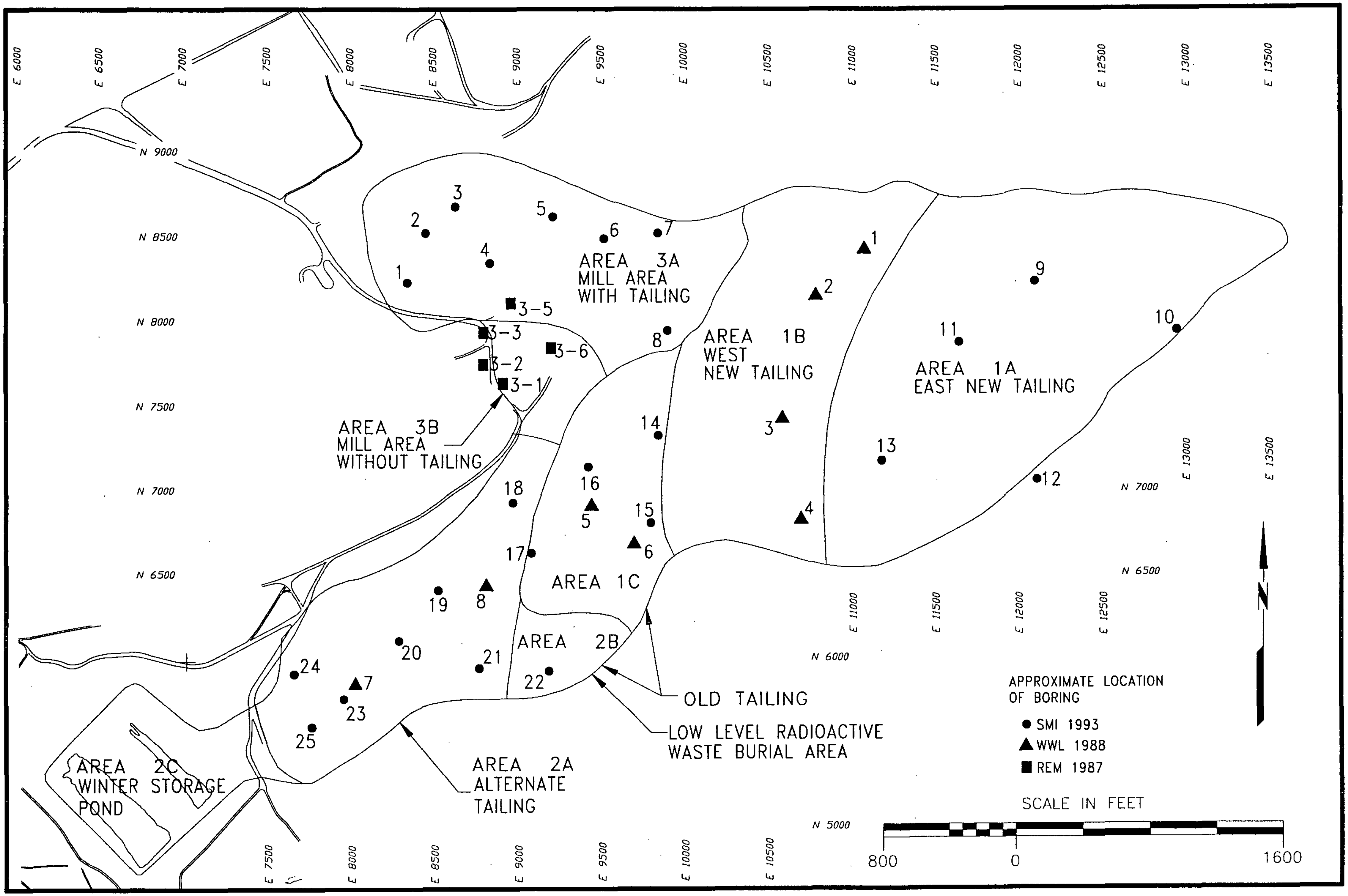
Figures



SMI
SHEPHERD MILLER, INC.

FIGURE G.1.1
FINAL RECLAMATION
COVER DESIGN

Date:	OCT., 1993
Project:	336
File:	COVER1



SMI
SHEPHERD MILLER, INC.

FIGURE G.1.2
TAILING AREA DELINEATIONS

Date: OCT., 1993
Project: 336
File: AREAS

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Attachment A
Radon Model Output

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

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        RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS                    ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: AREA1A.OUT

DESCRIPTION: AREA 1A - EAST NEW TAILING


                CONSTANTS

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


                GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS                 4
RADON FLUX LIMIT                             20           pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED             3
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         TAILING


THICKNESS                                    500          cm
POROSITY                                     .39
MEASURED MASS DENSITY                        1.62         g cm^-3
MEASURED RADIUM ACTIVITY                     280          pCi/g^-1
MEASURED EMANATION COEFFICIENT               .28
CALCULATED SOURCE TERM CONCENTRATION         6.839D-04    pCi cm^-3 s^-1
WEIGHT % MOISTURE                            1.5          %
MOISTURE SATURATION FRACTION                 .062
CALCULATED DIFFUSION COEFFICIENT             5.667D-02    cm^2 s^-1


LAYER 2         CODY SHALE @90% PROCTOR


THICKNESS                                    15.24        cm
POROSITY                                     .44
MEASURED MASS DENSITY                        1.59         g cm^-3
MEASURED SOURCE TERM CONCENTRATION           0            pCi cm^-3 s^-1
WEIGHT % MOISTURE                            16.9         %
MOISTURE SATURATION FRACTION                 .611
CALCULATED DIFFUSION COEFFICIENT             6.950D-03    cm^2 s^-1
```

```
LAYER 3       CODY SHALE @95% PROCTOR


THICKNESS                                 100          cm
POROSITY                                  .41
MEASURED MASS DENSITY                     1.65         g cm^-3
MEASURED SOURCE TERM CONCENTRATION        0            pCi cm^-3 s^-1
WEIGHT % MOISTURE                         16.9         %
MOISTURE SATURATION FRACTION              .680
CALCULATED DIFFUSION COEFFICIENT          4.068D-03    cm^2 s^-1


LAYER 4       BORROW SOIL


THICKNESS                                 30.5         cm
DEFAULT POROSITY                          .4
MEASURED MASS DENSITY                     1.55         g cm^-3
MEASURED RADIUM ACTIVITY                  1.1          pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT       .35
CALCULATED SOURCE TERM CONCENTRATION      3.133D-06    pCi cm^-3 s^-1
WEIGHT % MOISTURE                         2            %
MOISTURE SATURATION FRACTION              .077
CALCULATED DIFFUSION COEFFICIENT          5.395D-02    cm^2 s^-1




              DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

  N       F01         CN1       ICOST      CRITJ       ACC
  4   0.000D+00   0.000D+00       3      2.000D+01   1.000D-03

LAYER     DX          D           P           Q          XMS       RHO
  1   5.000D+02   5.667D-02   3.900D-01   6.839D-04   6.231D-02   1.620
  2   1.524D+01   6.950D-03   4.400D-01   0.000D+00   6.107D-01   1.590
  3   1.000D+02   4.068D-03   4.100D-01   0.000D+00   6.801D-01   1.650
  4   3.050D+01   5.395D-02   4.000D-01   3.133D-06   7.750D-02   1.550
```

```
BARE SOURCE FLUX FROM LAYER 1:  4.361D+02 pCi m^-2 s^-1


               RESULTS OF THE RADON DIFFUSION CALCULATIONS


               LAYER    THICKNESS    EXIT FLUX    EXIT CONC.
                          (cm)    (pCi m^-2 s^-1) (pCi l^-1)

                 1      5.000D+02    6.855D+01    2.745D+05
                 2      1.524D+01    4.850D+01    1.287D+05 }
                 3      6.635D+01    1.997D+01    1.484D+03 } 32.1 INCHES
                 4      3.050D+01    1.999D+01    0.000D+00
```

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

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        RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS                    ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: AREA1B.OUT

DESCRIPTION: AREA 1B - WEST NEW TAILING


            CONSTANTS

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


            GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS                4
RADON FLUX LIMIT                            20           pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED            3
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     TAILING


THICKNESS                                   500          cm
DEFAULT POROSITY                            .4
MEASURED MASS DENSITY                       1.55         g cm^-3
MEASURED RADIUM ACTIVITY                    450          pCi/g^-1
MEASURED EMANATION COEFFICIENT              .37
CALCULATED SOURCE TERM CONCENTRATION        1.355D-03    pCi cm^-3 s^-1
WEIGHT % MOISTURE                           1.5          %
MOISTURE SATURATION FRACTION                .058
CALCULATED DIFFUSION COEFFICIENT            5.758D-02    cm^2 s^-1


LAYER 2     CODY SHALE @90% PROCTOR


THICKNESS                                   15.24        cm
POROSITY                                    .44
MEASURED MASS DENSITY                       1.59         g cm^-3
MEASURED SOURCE TERM CONCENTRATION          0            pCi cm^-3 s^-1
WEIGHT % MOISTURE                           16.9         %
MOISTURE SATURATION FRACTION                .611
CALCULATED DIFFUSION COEFFICIENT            6.950D-03    cm^2 s^-1
```

```
LAYER 3       CODY SHALE @95% PROCTOR


THICKNESS                                  100         cm
POROSITY                                   .41
MEASURED MASS DENSITY                      1.65        g cm^-3
MEASURED SOURCE TERM CONCENTRATION         0           pCi cm^-3 s^-1
WEIGHT % MOISTURE                          16.9        %
MOISTURE SATURATION FRACTION               .680
CALCULATED DIFFUSION COEFFICIENT           4.068D-03   cm^2 s^-1


LAYER 4       BORROW SOIL


THICKNESS                                  30.5        cm
DEFAULT POROSITY                           .4
MEASURED MASS DENSITY                      1.55        g cm^-3
MEASURED RADIUM ACTIVITY                   1.1         pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       3.133D-06   pCi cm^-3 s^-1
WEIGHT % MOISTURE                          2           %
MOISTURE SATURATION FRACTION               .077
CALCULATED DIFFUSION COEFFICIENT           5.395D-02   cm^2 s^-1




              DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

  N       F01         CN1        ICOST      CRITJ       ACC
  4   0.000D+00   0.000D+00       3      2.000D+01   1.000D-03

LAYER     DX          D           P           Q          XMS        RHO
  1   5.000D+02   5.758D-02   4.000D-01   1.355D-03   5.812D-02   1.550
  2   1.524D+01   6.950D-03   4.400D-01   0.000D+00   6.107D-01   1.590
  3   1.000D+02   4.068D-03   4.100D-01   0.000D+00   6.801D-01   1.650
  4   3.050D+01   5.395D-02   4.000D-01   3.133D-06   7.750D-02   1.550
```

```
BARE SOURCE FLUX FROM LAYER 1:  8.932D+02 pCi m^-2 s^-1


               RESULTS OF THE RADON DIFFUSION CALCULATIONS


               LAYER     THICKNESS     EXIT FLUX     EXIT CONC.
                           (cm)     (pCi m^-2 s^-1) (pCi l^-1)

                 1       5.000D+02     1.317D+02     5.501D+05
                 2       1.524D+01     9.142D+01     2.598D+05 \
                 3       9.574D+01     1.996D+01     1.483D+03 /  43.7 inches
                 4       3.050D+01     1.998D+01     0.000D+00
```

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

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        RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS                  ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: AREA1C.OUT

DESCRIPTION: AREA 1C & 2B - OLD TAILING


              CONSTANTS

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


              GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS               4
RADON FLUX LIMIT                           20           pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED           3
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       TAILING


THICKNESS                                  500          cm
POROSITY                                   .39
MEASURED MASS DENSITY                      1.61         g cm^-3
MEASURED RADIUM ACTIVITY                   341          pCi/g^-1
MEASURED EMANATION COEFFICIENT             .25
CALCULATED SOURCE TERM CONCENTRATION       7.391D-04    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          3.58         %
MOISTURE SATURATION FRACTION               .148
CALCULATED DIFFUSION COEFFICIENT           4.239D-02    cm^2 s^-1


LAYER 2       CODY SHALE @90% PROCTOR


THICKNESS                                  15.24        cm
POROSITY                                   .44
MEASURED MASS DENSITY                      1.59         g cm^-3
MEASURED SOURCE TERM CONCENTRATION         0            pCi cm^-3 s^-1
WEIGHT % MOISTURE                          16.9         %
MOISTURE SATURATION FRACTION               .611
CALCULATED DIFFUSION COEFFICIENT           6.950D-03    cm^2 s^-1
```

```
LAYER 3       CODY SHALE @95% PROCTOR


THICKNESS                              100         cm
POROSITY                               .41
MEASURED MASS DENSITY                  1.65        g cm^-3
MEASURED SOURCE TERM CONCENTRATION     0           pCi cm^-3 s^-1
WEIGHT % MOISTURE                      16.9        %
MOISTURE SATURATION FRACTION           .680
CALCULATED DIFFUSION COEFFICIENT       4.068D-03   cm^2 s^-1


LAYER 4       BORROW SOIL


THICKNESS                              30.5        cm
DEFAULT POROSITY                       .4
MEASURED MASS DENSITY                  1.55        g cm^-3
MEASURED RADIUM ACTIVITY               1.1         pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT    .35
CALCULATED SOURCE TERM CONCENTRATION   3.133D-06   pCi cm^-3 s^-1
WEIGHT % MOISTURE                      2           %
MOISTURE SATURATION FRACTION           .077
CALCULATED DIFFUSION COEFFICIENT       5.395D-02   cm^2 s^-1



             DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

  N       F01        CN1       ICOST      CRITJ       ACC
  4   0.000D+00  0.000D+00       3      2.000D+01  1.000D-03

LAYER     DX          D          P          Q         XMS       RHO
  1   5.000D+02  4.239D-02  3.900D-01  7.391D-04  1.478D-01  1.610
  2   1.524D+01  6.950D-03  4.400D-01  0.000D+00  6.107D-01  1.590
  3   1.000D+02  4.068D-03  4.100D-01  0.000D+00  6.801D-01  1.650
  4   3.050D+01  5.395D-02  4.000D-01  3.133D-06  7.750D-02  1.550
```

```
BARE SOURCE FLUX FROM LAYER 1:  4.088D+02 pCi m^-2 s^-1


                    RESULTS OF THE RADON DIFFUSION CALCULATIONS


                    LAYER    THICKNESS    EXIT FLUX     EXIT CONC.
                               (cm)     (pCi m^-2 s^-1) (pCi l^-1)

                      1      5.000D+02    7.589D+01     2.866D+05
                      2      1.524D+01    5.344D+01     1.443D+05
                      3      7.100D+01    1.996D+01     1.483D+03
                      4      3.050D+01    1.999D+01     0.000D+00
```

} 33.9 inches

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

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        RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS                    ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: AREA2A.OUT

DESCRIPTION: AREA 2A - ALTERNATE TAILING AREA


              CONSTANTS

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


              GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS              4
RADON FLUX LIMIT                          20           pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED          3
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       TAILING


THICKNESS                                 500          cm
POROSITY                                  .36
MEASURED MASS DENSITY                     1.64         g cm^-3
MEASURED RADIUM ACTIVITY                  448          pCi/g^-1
MEASURED EMANATION COEFFICIENT            .25
CALCULATED SOURCE TERM CONCENTRATION      1.071D-03    pCi cm^-3 s^-1
WEIGHT % MOISTURE                         2.15         %
MOISTURE SATURATION FRACTION              .098
CALCULATED DIFFUSION COEFFICIENT          4.977D-02    cm^2 s^-1


LAYER 2       CODY SHALE @90% PROCTOR


THICKNESS                                 15.24        cm
POROSITY                                  .44
MEASURED MASS DENSITY                     1.59         g cm^-3
MEASURED SOURCE TERM CONCENTRATION        0            pCi cm^-3 s^-1
WEIGHT % MOISTURE                         16.9         %
MOISTURE SATURATION FRACTION              .611
CALCULATED DIFFUSION COEFFICIENT          6.950D-03    cm^2 s^-1
```

```
LAYER 3        CODY SHALE @95% PROCTOR


THICKNESS                                100         cm
POROSITY                                 .41
MEASURED MASS DENSITY                    1.65        g cm^-3
MEASURED SOURCE TERM CONCENTRATION       0           pCi cm^-3 s^-1
WEIGHT % MOISTURE                        16.9        %
MOISTURE SATURATION FRACTION             .680
CALCULATED DIFFUSION COEFFICIENT         4.068D-03   cm^2 s^-1


LAYER 4        BORROW SOIL


THICKNESS                                30.5        cm
DEFAULT POROSITY                         .4
MEASURED MASS DENSITY                    1.55        g cm^-3
MEASURED RADIUM ACTIVITY                 1.1         pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT      .35
CALCULATED SOURCE TERM CONCENTRATION     3.133D-06   pCi cm^-3 s^-1
WEIGHT % MOISTURE                        2           %
MOISTURE SATURATION FRACTION             .077
CALCULATED DIFFUSION COEFFICIENT         5.395D-02   cm^2 s^-1




               DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

  N       F01        CN1       ICOST       CRITJ       ACC
  4    0.000D+00  0.000D+00      3      2.000D+01  1.000D-03

LAYER     DX          D          P          Q          XMS       RHO
  1    5.000D+02  4.977D-02  3.600D-01  1.071D-03  9.794D-02  1.640
  2    1.524D+01  6.950D-03  4.400D-01  0.000D+00  6.107D-01  1.590
  3    1.000D+02  4.068D-03  4.100D-01  0.000D+00  6.801D-01  1.650
  4    3.050D+01  5.395D-02  4.000D-01  3.133D-06  7.750D-02  1.550
```

```
BARE SOURCE FLUX FROM LAYER 1:  5.920D+02 pCi m^-2 s^-1


               RESULTS OF THE RADON DIFFUSION CALCULATIONS


               LAYER     THICKNESS     EXIT FLUX     EXIT CONC.
                           (cm)     (pCi m^-2 s^-1) (pCi l^-1)

                 1       5.000D+02     1.046D+02     4.201D+05
                 2       1.524D+01     7.293D+01     2.042D+05 }  39.6 INCHES
                 3       8.545D+01     1.997D+01     1.484D+03 }
                 4       3.050D+01     1.999D+01     0.000D+00
```

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

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         RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS                          ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: AREA3A.OUT

DESCRIPTION: AREA 3A - MILL AREA WITH TAILING


              CONSTANTS

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


              GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS                4
RADON FLUX LIMIT                            20           pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED            3
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       TAILING


THICKNESS                                   500          cm
POROSITY                                    .37
MEASURED MASS DENSITY                       1.65         g cm^-3
MEASURED RADIUM ACTIVITY                    88           pCi/g^-1
MEASURED EMANATION COEFFICIENT              .17
CALCULATED SOURCE TERM CONCENTRATION        1.401D-04    pCi cm^-3 s^-1
WEIGHT % MOISTURE                           2.15         %
MOISTURE SATURATION FRACTION                .096
CALCULATED DIFFUSION COEFFICIENT            5.027D-02    cm^2 s^-1


LAYER 2       CODY SHALE @90% PROCTOR


THICKNESS                                   15.24        cm
POROSITY                                    .44
MEASURED MASS DENSITY                       1.59         g cm^-3
MEASURED SOURCE TERM CONCENTRATION          0            pCi cm^-3 s^-1
WEIGHT % MOISTURE                           16.9         %
MOISTURE SATURATION FRACTION                .611
CALCULATED DIFFUSION COEFFICIENT            6.950D-03    cm^2 s^-1
```

```
LAYER 3       CODY SHALE @95% PROCTOR


THICKNESS                              100         cm
POROSITY                               .41
MEASURED MASS DENSITY                  1.65        g cm^-3
MEASURED SOURCE TERM CONCENTRATION     0           pCi cm^-3 s^-1
WEIGHT % MOISTURE                      16.9        %
MOISTURE SATURATION FRACTION           .680
CALCULATED DIFFUSION COEFFICIENT       4.068D-03   cm^2 s^-1


LAYER 4       BORROW SOIL


THICKNESS                              30.5        cm
DEFAULT POROSITY                       .4
MEASURED MASS DENSITY                  1.55        g cm^-3
MEASURED RADIUM ACTIVITY               1.1         pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT    .35
CALCULATED SOURCE TERM CONCENTRATION   3.133D-06   pCi cm^-3 s^-1
WEIGHT % MOISTURE                      2           %
MOISTURE SATURATION FRACTION           .077
CALCULATED DIFFUSION COEFFICIENT       5.395D-02   cm^2 s^-1




              DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

  N       F01        CN1       ICOST      CRITJ       ACC
  4    0.000D+00  0.000D+00      3      2.000D+01  1.000D-03

LAYER      DX         D          P          Q         XMS       RHO
  1    5.000D+02  5.027D-02  3.700D-01  1.401D-04  9.588D-02  1.650
  2    1.524D+01  6.950D-03  4.400D-01  0.000D+00  6.107D-01  1.590
  3    1.000D+02  4.068D-03  4.100D-01  0.000D+00  6.801D-01  1.650
  4    3.050D+01  5.395D-02  4.000D-01  3.133D-06  7.750D-02  1.550
```

```
BARE SOURCE FLUX FROM LAYER 1:  7.995D+01 pCi m^-2 s^-1


                    RESULTS OF THE RADON DIFFUSION CALCULATIONS


                    LAYER     THICKNESS     EXIT FLUX     EXIT CONC.
                                 (cm)     (pCi m^-2 s^-1) (pCi l^-1)

                      1       5.000D+02     2.385D+01     4.681D+04
                      2       1.524D+01     2.076D+01     1.656D+04
                      3       1.114D+01     1.997D+01     1.484D+03
                      4       3.050D+01     1.999D+01     0.000D+00
```

} 10.4 INCHES

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

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        RADON FLUX, CONCENTRATION AND TAILINGS COVER THICKNESS                ARE CALCULATED FOR MULTIPLE LAYERS

OUTPUT FILE: AREA3B.OUT

DESCRIPTION: AREA 3B - MILL AREA WITHOUT TAILING


              CONSTANTS

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


              GENERAL INPUT PARAMETERS

LAYERS OF COVER AND TAILINGS               5
RADON FLUX LIMIT                           20           pCi m^-2 s^-1
NO. OF THE LAYER TO BE OPTIMIZED           4
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       TAILING


THICKNESS                                  500          cm
DEFAULT POROSITY                           .4
MEASURED MASS DENSITY                      1.57         g cm^-3
MEASURED RADIUM ACTIVITY                   5.5          pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       1.587D-05    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          1.5          %
MOISTURE SATURATION FRACTION               .059
CALCULATED DIFFUSION COEFFICIENT           5.744D-02    cm^2 s^-1


LAYER 2       TAILING


THICKNESS                                  30.5         cm
DEFAULT POROSITY                           .4
MEASURED MASS DENSITY                      1.57         g cm^-3
MEASURED RADIUM ACTIVITY                   20.3         pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT        .35
CALCULATED SOURCE TERM CONCENTRATION       5.856D-05    pCi cm^-3 s^-1
WEIGHT % MOISTURE                          1.5          %
MOISTURE SATURATION FRACTION               .059
CALCULATED DIFFUSION COEFFICIENT           5.744D-02    cm^2 s^-1
```

```
LAYER 3       CODY SHALE @90% PROCTOR


THICKNESS                                 15.24         cm
POROSITY                                  .44
MEASURED MASS DENSITY                     1.59          g cm^-3
MEASURED SOURCE TERM CONCENTRATION        0             pCi cm^-3 s^-1
WEIGHT % MOISTURE                         16.9          %
MOISTURE SATURATION FRACTION              .611
CALCULATED DIFFUSION COEFFICIENT          6.950D-03     cm^2 s^-1


LAYER 4       CODY SHALE @95% PROCTOR


THICKNESS                                 100           cm
POROSITY                                  .41
MEASURED MASS DENSITY                     1.65          g cm^-3
MEASURED SOURCE TERM CONCENTRATION        0             pCi cm^-3 s^-1
WEIGHT % MOISTURE                         16.9          %
MOISTURE SATURATION FRACTION              .680
CALCULATED DIFFUSION COEFFICIENT          4.068D-03     cm^2 s^-1


LAYER 5       BORROW SOIL


THICKNESS                                 30.5          cm
DEFAULT POROSITY                          .4
MEASURED MASS DENSITY                     1.55          g cm^-3
MEASURED RADIUM ACTIVITY                  1.1           pCi/g^-1
DEFAULT LAYER EMANATION COEFFICIENT       .35
CALCULATED SOURCE TERM CONCENTRATION      3.133D-06     pCi cm^-3 s^-1
WEIGHT % MOISTURE                         2             %
MOISTURE SATURATION FRACTION              .077
CALCULATED DIFFUSION COEFFICIENT          5.395D-02     cm^2 s^-1
```

```
              DATA SENT TO THE FILE 'RNDATA' ON DRIVE A:

  N       F01         CN1        ICOST       CRITJ        ACC
  5    0.000D+00   0.000D+00       4       2.000D+01   1.000D-03

LAYER     DX          D           P           Q           XMS        RHO
  1    5.000D+02   5.744D-02   4.000D-01   1.587D-05   5.887D-02   1.570
  2    3.050D+01   5.744D-02   4.000D-01   5.856D-05   5.887D-02   1.570
  3    1.524D+01   6.950D-03   4.400D-01   0.000D+00   6.107D-01   1.590
  4    1.000D+02   4.068D-03   4.100D-01   0.000D+00   6.801D-01   1.650
  5    3.050D+01   5.395D-02   4.000D-01   3.133D-06   7.750D-02   1.550

BARE SOURCE FLUX FROM LAYER 1:  1.045D+01 pCi m^-2 s^-1


              RESULTS OF THE RADON DIFFUSION CALCULATIONS


              LAYER    THICKNESS     EXIT FLUX     EXIT CONC.
                          (cm)     (pCi m^-2 s^-1) (pCi l^-1)

                1      5.000D+02     9.987D-01     6.833D+03
                2      3.050D+01     6.440D+00     6.341D+03
                3      1.524D+01     6.150D+00     5.148D+02   ← 6" NOT REQUIRED
                4      0.000D+00     6.150D+00     4.666D+02
                5      3.050D+01     6.418D+00     0.000D+00
```

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Attachment B
Radon Model Input Parameter Calculations

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Summary of Tailing Areas

Area 1A	East New Tailing
Area 1B	West New Tailing
Area 1C	Old Tailing
Area 2A	Alternate Tailing
Area 2B	Old Tailing (Includes low level radioactive waste burial area)
Area 2C	Winter storage pond area
Area 3A	Mill area with tailing
Area 3B	Mill area without tailing

AREA 1A - EAST NEW TAILING AREA

RADIUM ACTIVITY - See following page for DATA information.

BORING/SAMPLE	DEPTH	RADIUM ACTIVITY (pCi/g)
SMI 9	2-2'8	353.2
SMI 10	4-5'	264.0
SMI 11	6-7' 8-9'	419.3 179.3
SMI 12	10.5-11' 14-15'	381.7 201.2
SMI 13	2-3' 14-15'	184.4 84.8
WWL 1	2-3.5' 4-5.5' 7-8.5'	176 103 72
WWL 2	2-3.5' 4-5.5' 7-8.5' 9-10.5' 13-13.5' 14-15.5' 17-18.5'	221 483 59 57 157 49 37
WWL 3	2-3.5' 4-5' 7-8.5'	34 53 45
WWL-4	2-3.5' 4-5' 7-8.5'	88 251 61
WWL SS-1 SS-2 SS-4 SS-5 SS-7 SS-8 SS-9 SS-10 SS-12 SS-13 SS-14	N/A	513 523 416 733 91 1032 364 461 460 774 627
NEW EMBANKMENT	N/A	61
AVERAGE RADIUM ACTIVITY		**280 pCi/g**

AREA 1A - EAST NEW TAILING AREA (CONT.)

Radium Activity Data:

SMI 1993; Borings 9, 10, 11, 12 & 13; see Appendix A, Section A.6; Page A-84

WWL 1988; Surface Samples 1, 2, 4, 5, 7, 8, 9, 10, 12, 13, 14 & new embankment surface sample; see Appendix A, Section A-1, Page A-15

WWL 1988; Borings 1 (top 9'), 2 (top 19'), 3 (top 12') & 4 (top 9'); see Appendix A, Section A.1, Page A-13

EMANATION COEFFICIENT

DATA: WWL 1988; Borings 1 (top 9'), 2 (top 19'), 3 (top 12') & 4 (top 9') see Appendix A, Section A.1, Page A-13

DATA: WWL 1988; Surface sample 5, new embankment surface sample see Appendix A, Section A.1, Page A-15

BORING/SAMPLE	DEPTH	EMANATION COEFFICIENT
WWL 1	7-8.5'	0.28
WWL 2	2-3.5' 7-8.5'	0.34 0.27
WWL 3	4-5'	0.18
WWL 4	4-5'	0.27
WWL SS-5	N/A	0.29
NEW EMBANKMENT	N/A	0.30
AVERAGE EMANATION COEFFICIENT		**0.28**

SPECIFIC GRAVITY

DATA: None - Use default value

SPECIFIC GRAVITY = 2.65

AREA 1A - EAST NEW TAILING AREA (CONT.)

DRY DENSITY

<table>
<tr><td colspan="3">DATA: SMI 1993; Borings 9, 10, 11, 12
see Appendix A, Section A.6; Page A-79</td></tr>
<tr><th>BORING</th><th>DEPTH</th><th>DRY DENSITY (pcf)</th></tr>
<tr><td>SMI 9</td><td>4'6-4'9</td><td>86.1</td></tr>
<tr><td>SMI 10</td><td>12'9-13'</td><td>106.8</td></tr>
<tr><td>SMI 11</td><td>8'9-9'</td><td>108.3</td></tr>
<tr><td>SMI 12</td><td>4'9-5'</td><td>103.8</td></tr>
<tr><td colspan="2">**AVERAGE DRY DENSITY**</td><td>**101.3 (1.62 g/cm^3)**</td></tr>
</table>

POROSITY

Calculated by $\eta = 1 - \rho/G_s = 1 - (1.62/2.65) = 0.37$

POROSITY = 0.39

AREA 1B - WEST NEW TAILING AREA

RADIUM ACTIVITY

DATA: WWL 1988; Borings 1, 2, 3 & 4; see Appendix A, section A.1, Page A-13

BORING	ORIGINAL DEPTH	REGRADED DEPTH	RADIUM ACTIVITY (pCi/g)
WWL 1	9-10.5′	0-1.5′	47
	12-13.5′	3-4.5′	97
	19-20′	10-11′	764
WWL 2	19-20.5′	0-1.5′	115
	22-23′	3-4′	828
WWL 3	14-15′	2-3′	1140
	15-15.5′	3-3.5′	159
	19-20.5′	7-8.5′	1009
	22-23.5′	10-11.5′	107
	24-25′	12-13′	88
	25-26′	13-14′	780
WWL 4	14-15.5′	5-6.5′	85
	22-23′	13-14′	1001
	23-23.5′	14-14.5′	80
AVERAGE RADIUM ACTIVITY			**450 pCi/g**

EMANATION COEFFICIENT

DATA: WWL 1988; Boring 3; see Appendix A, Section A.1, Page A-13

BORING	ORIGINAL DEPTH	REGRADED DEPTH	EMANATION COEFFICIENT
WWL	14-15′	2-3′	**0.37**

SPECIFIC GRAVITY

DATA: WWL 1988; Boring 3; see Appendix A, Section A.1, Page A-12

BORING	ORIGINAL DEPTH	REGRADED DEPTH	SPECIFIC GRAVITY
WWL 3	24-25′	12-13′	**2.59**

AREA 1B - WEST NEW TAILING AREA (CONT.)

LONG-TERM MOISTURE

DATA: 15-bar laboratory value from Canonie's coarse tailings sample, listed as sample 7; See Appendix A, Section A.2, Page A-24

LONG-TERM MOISTURE = 1.5%

POROSITY

DATA: None - Use default value

POROSITY = 0.4

DRY DENSITY

Calculated from $\rho = G_s(1-\eta) = 2.59(1 - 0.4) = 1.55\ \text{g/cm}^3$

DRY DENSITY = 1.55 g/cm^3

AREA 1C & 2B - OLD TAILING AREA

RADIUM ACTIVITY

DATA: SMI 1993; Borings 14, 15, 16, 21 & 22
see Appendix A, Section A.6; Pages A-84, A-85

DATA: WWL 1988; Borings 5 & 6
see Appendix A, Section A.1, Page A-14

BORING	DEPTH	RADIUM ACTIVITY (pCi/g)
SMI 14	14-14.5′	60.5
SMI 15	10-11′	440.7
	12-13′	1204.1
SMI 16	2-3′	728.3
	6-7′	8.0
SMI 21	2-3′	6.6
	6-7′	396.6
	10-11′	318.3
SMI 22	6-7′	21.8
	14-15′	753.1
WWL 5	2-3.5′	510
	7-8.5′	189
	9-10.5′	262
	14-15.5′	219
WWL 6	2-3.5′	215
	4-5.5′	141
	9-10.5′	376
	12-13.5′	293
AVERAGE RADIUM ACTIVITY		341

AREA 1C &2B - OLD TAILING AREA (CONT.)

EMANATION COEFFICIENT

DATA: SMI 1993; Tailing composite sample #1
see Appendix A, Section A.6; Page A-88

DATA: WWL 1988; Boring 5
see Appendix A, Section A.1, Page A-14

BORING	DEPTH	EMANATION COEFFICIENT
Composite #1	N/A	0.22
WWL 5	7-8.5′	0.27
AVERAGE EMANATION COEFFICIENT		**0.25**

SPECIFIC GRAVITY

DATA: SMI 1993; Tailing composite #1; see Appendix A, Section A.6; Page A-87

SPECIFIC GRAVITY = 2.65

LONG-TERM MOISTURE

DATA: SMI 1993; Tailing composite #1 - laboratory 15-bar value see Appendix A, Section A.6; Page A-89

LONG-TERM MOISTURE CONTENT = 3.58%

AREA 1C & 2B - OLD TAILING AREA (CONT.)

DRY DENSITY

DATA: SMI 1993; Borings 14, 15, 16, 21 & 22
see Appendix A, Section A.6; Pages A-79, A-80

BORING	DEPTH	DRY DENSITY (pcf)
SMI 14	4'6-4'9	106.9
SMI 15	8'9-9' 12'6-12'9	107.8 87.1
SMI 16	4'-4'3 8'9-9'	86.2 99.2
SMI 21	4'-4'3	104.6
SMI 22	8'-8'3 12'9-13'	106.3 105.3
AVERAGE DRY DENSITY		**100.4 (1.61 g/cm^3)**

POROSITY

Calculated by $\eta = 1 - \rho/G_s = 1 - (1.61/2.65) = 0.39$

POROSITY = 0.39

AREA 2A - ALTERNATE TAILING AREA

RADIUM ACTIVITY

DATA: SMI 1993; Borings 17, 18, 19, 20, 23, 24, 25;
See Appendix A, Section A.6; Pages A-84 A85

DATA: WWL 1988; Borings 7, 8 & old embankment sample
See Appendix A, Section A.1, Page A-14

BORING	DEPTH	RADIUM ACTIVITY (pCi/g)
SMI 17	6-7′	150.3
SMI 18	4-5′	186.4
	8-9′	9.0
	10-12′	205.8
	14-15′	12.8
SMI 19	2-3′	286.6
	6-7′	321.2
	10-11′	177.1
SMI 20	2-3′	85.8
SMI 23	2-3′	9.3
	6-6.5′	24.5
	8-9′	131.4
	14-15′	5.6
SMI 24	4-5′	146.9
SMI 25	2-3′	283.8
	6-7′	98.3
WWL 7	6-7.5′	1350
	9-10.5′	3522
	12-13.5′	2566
WWL 8	0-1.5′	15
	3-4.5′	226
	7.5-8.5′	911
	8.5-9′	204
	9-10.5′	304
	10.5-12′	278
OLD EMBANKMENT	N/A	144
AVERAGE RADIUM ACTIVITY		**448 pCi/g**

G'SU

AREA 2A - ALTERNATE TAILING AREA (CONT.)

EMANATION COEFFICIENT

DATA: SMI 1993: Tailing composite #4
see Appendix A, Section A.6; Page A-88

DATA: WWL 1988: Borings 7, 8 & new embankment sample
see Appendix A, Section A.1, Page A-14

BORING	DEPTH	EMANATION COEFFICIENT
Composite #4	N/A	0.17
WWL 7	6'-7.5'	0.31
WWL 8	3-4.5' 7.5-8.5' 8.5-9.5'	0.24 0.27 0.23
New embankment	N/A	0.30
AVERAGE EMANATION COEFFICIENT		**0.25**

SPECIFIC GRAVITY

DATA: SMI 1993: Tailing composite sample #4
See Appendix A, Section A.6; Page A-87

SPECIFIC GRAVITY = 2.62

LONG-TERM MOISTURE

DATA: SMI 1993: Tailing composite sample #4 - laboratory 15-bar value
See Appendix A, Section A.6, Page A-89

LONG-TERM MOISTURE CONTENT = 2.15%

AREA 2A - ALTERNATE TAILING AREA (CONT.)

DRY DENSITY

DATA: SMI 1993; Borings 17, 18, 19, 20, 23, 24 & 25
See Appendix A, Section A.6; Pages A-79, A-80

BORING	DEPTH	DRY DENSITY (pcf)
17	12-12'3	105.0
18	12'9-13'	94.7
19	8'9-9'	102.3
20	4'9-5'	103.1
23	4'9-5'	88.8
24	8'9-9' 12'6-12'9	104.5 107.7
25	4'9-5'	111.5
AVERAGE DRY DENSITY		**102.2 (1.64 g/cm^3)**

POROSITY

Calculated from $\eta = 1 - \rho/G_s = 1 - (1.64/2.62) = 0.36$

POROSITY = 0.36

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AREA 3A - MILL AREA WITH TAILING

RADIUM ACTIVITY

DATA: SMI 1993 Borings 1, 2, 3, 4, 5, 6, 7 & 8;
see Appendix A, Section A6, page A-84

BORING	DEPTH	RADIUM ACTIVITY (pCi/g)
1	2-3′	132.6
1	8-9′	2.5
1	14-15′	55.1
2	3-4′	128.1
2	9-10′	283.3
2	12-13′	24.4
3	4-5′	3.8
3	6-7′	5.8
4	2-3′	95.5
4	8-9′	33.2
4	10-11′	36.7
5	8-9′	138.1
5	10-11′	90.2
6	8-9′	152.3
6	10-11′	66.2
7	14-15′	91.0
8	2-3′	45.0
8	4-5′	2.0
8	12-13′	285.3
AVERAGE RADIUM ACTIVITY		**88.0 pCi/g**

AREA 3A - MILL AREA WITH TAILING (CONT.)

DRY DENSITY

DATA: SMI 1993 Borings 1, 2, 3, 4, 5, 6, 7 & 8;
see Appendix A, Section A.6; Page A-79

BORING	DEPTH	DRY DENSITY (pcf)
1	12'6-12'9	106.5
2	9'-9'3	96.5
3	8'-8'3	101.2
4	1-'-10'3	92.4
5	4'6-4'9	105.8
6	6'9-7'	108.1
6	10'-10'3	113.3
7	4'-4'3	95.5
8	2'9-3'	105.8
AVERAGE DRY DENSITY		**103.0 (1.65 g/cm^3)**

EMANATION COEFFICIENT, SPECIFIC GRAVITY & LONG-TERM MOISTURE

DATA: SMI 1992: Tailing Composite Sample #4
See Appendix A, Section A.6; Page A-87, A-88, A-89

EMANATION COEFFICIENT = 0.17

SPECIFIC GRAVITY = 2.62

LONG TERM MOISTURE = 2.15%

POROSITY

Calculated from $\eta = 1 - \rho/G_s = 1 - (1.65/2.62) = 0.37$

POROSITY = 0.37

AREA 3B - MILL AREA WITHOUT IMPORTED TAILING

RADIUM ACTIVITY - TOP 12 INCHES

DATA: REM 1987; Borings 3-1, 3-2, 3-3, 3-5, 3-6;
See Appendix A, Section A.9; Page A-175

DATA: Based on Canonie's 1989 composite surface sample C-3;
See Appendix A, Section A.3, Page A-38

BORING	DEPTH	RADIUM ACTIVITY (pCi/g)
3-1	0-6" 6-12"	1.9 8.9
3-2	0-6" 6-12"	0.9 1.1
3-3	0-6" 6-12"	18.6 4.5
3-5	0-6" 6-12"	33.4 38.5
3-6	0-6" 6-12"	47.1 42.5
Canonie C-3	N/A	26
AVERAGE RADIUM ACTIVITY		**20.3 pCi/g**

Note: Average radium activity is attributed to windblown tailing.

AREA 3B - MILL AREA WITHOUT IMPORTED TAILING (CONT.)

RADIUM ACTIVITY - LOWER 14 FEET

DATA: REM 1987; Borings 3-1, 3-2, 3-3, 3-5, 3-6;
See Appendix A, Section A.9; Page A-175

BORING	DEPTH	RADIUM ACTIVITY (pCi/g)
3-1	12-18"	6.2
	3-4'	7.5
	4-5'	7.8
	5-6'	6.8
	6-7'	7.4
3-2	12-18"	1.1
	3-4'	1.4
	4-5'	1.1
	5-6'	1.1
	6-7'	1.2
	7-8'	1.2
	8-9'	1.0
3-3	12-18"	1.4
	3-4'	0.3
	4-5'	0.9
	5-6'	1.5
	6-7'	1.5
	7-8'	2.0
3-5	12-18"	3.0
	3-4'	1.0
	4-5'	1.3
	5-6'	1.3
	6-7'	0.9
	7-8'	1.4
	8-9'	1.1
3-6	12-18"	14.1
	3-4'	28.5
	4-5'	16.4
	5-6'	13.7
	6-7'	15.0
	7-8'	11.2
	8-9'	14.9
AVERAGE RADIUM ACTIVITY		**5.5 pCi/g**

G-36

AREA 3B - MILL AREA WITHOUT IMPORTED TAILING (CONT.)

EMANATION COEFFICIENT

DATA: None - Use default value

EMANATION COEFFICIENT = 0.35

SPECIFIC GRAVITY

DATA: Canonie's 1989 composite surface sample C-4, listed as sample 5; See Appendix A, Section A.2, Page A-23

SPECIFIC GRAVITY = 2.61

LONG-TERM MOISTURE

DATA: 15-bar laboratory value from Canonie's coarse tailings sample, listed as sample 7; See Appendix A, Section A.2, Page A-24

LONG-TERM MOISTURE = 1.5%

POROSITY

DATA: None - Use default value

POROSITY = 0.4

DRY DENSITY

Calculated from $\rho = G_s(1-\eta) = 2.61(1 - 0.4) = 1.57$ g/cm^3

DRY DENSITY = 1.57 g/cm^3

G5 /

RADON BARRIER LAYERS

CODY SHALE COMPOSITE #2

SPECIFIC GRAVITY

DATA: Laboratory result on composite sample; see Appendix A, Section A.8; Page A-155

SPECIFIC GRAVITY = 2.78

DRY DENSITY

DATA: 95% and 90% of standard Proctor density; see Appendix A, Section A.8 ; Page A-155

90% DRY DENSITY = 1.59 g/cm^3
95% DRY DENSITY = 1.65 g/cm^3

POROSITY

Calculated by $\eta = 1 - \rho/G_s = 1 - (1.65/2.78) = 0.41$

95% POROSITY = 0.41
90% POROSITY = 0.44

MOISTURE CONTENT

DATA: Laboratory 15-bar value for composite sample; see Appendix A, Section A.8 ; Page A-155

MOISTURE CONTENT = 16.9%

G-58

BORROW SOIL LAYER

RADIUM ACTIVITY

DATA: Assumed

RADIUM ACTIVITY = 1.1 pCi/g

EMANATION COEFFICIENT

DATA: Default value

EMANATION COEFFICIENT = 0.35

SPECIFIC GRAVITY AND POROSITY

DATA: None - Use default values

SPECIFIC GRAVITY = 2.65

DRY DENSITY

Calculated from $\rho = G_s(1-\eta) = 2.59(1 - 0.4) = 1.55$ g/cm^3

DRY DENSITY = 1.55 g/cm^3

MOISTURE CONTENT

DATA: Assumed for typical sandy materials

MOISTURE CONTENT = 2%

APPENDIX H

RADIOLOGICAL TESTING PROCEDURES

I-1/H-1

INTRODUCTION

A new method has been developed and tested for measuring radon gas diffusion coefficients. The method is based on measurement of the non-equilibrium or transient movement of radon through a sample material, rather than on the more traditional steady-state transport of radon through the sample. The present application and evaluation of this method was conducted as part of a larger research and development project aimed at reducing radon emissions from uranium mill tailings piles. This project is being conducted for the U.S. Nuclear Regulatory Commission under a subcontract with Pacific Northwest Laboratory (PNL).(a)

Due to the potential public health hazards from atmospheric radon (^{222}Rn) and its decay products, it is important to minimize its release into the atmosphere. Uranium mill tailings produce radon at nearly constant rates over periods of thousands of years; therefore permanent covers are being sought for tailings piles to reduce the fraction of the radon gas which reaches the atmosphere. The short (3.8-day) half-life of radon allows it to decay appreciably in the cover as long as its diffusion time through the cover is several days or longer. The radon diffusion coefficients of soils and other potential cover materials are therefore necessary to choose the proper tailings cover thickness and other design parameters to minimize radon release.

The present transient-diffusion measurement technique was developed and tested for two purposes. First, it could potentially provide improved capabilities over many existing methods, including lower cost, higher precision,

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(a) Operated by Battelle Memorial Institute

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"COMPARISION OF RADON DIFFUSION COEFFICIENT BY TRANSIENT-DIFFUSION AND STEADY-STATE LABORATORY METHODS" of both methods. Second, it could potentially provide improved capabilities over many existing methods, including lower cost, higher precision, shorter experiment time requirements and greater laboratory versatility.

The capabilities of the present transient-diffusion system are attractive in comparison with many traditional diffusion measurements. Typical equilibration times for large soil test columns in previous work(1-3) were one to two months or longer, and sample requirements were often on the order of hundreds of kilograms or more. Smaller-scale diffusion experiments have been proposed(4) and recently developed and tested.(5) These were equilibrium diffusion measurements, and typically utilized only a few kilograms of sample material. Because of the small sample size, equilibrium was quickly achieved (~3 days). The present transient measurements utilize samples of similar size, and can be completed over time intervals of one to two days for diffusion coefficients as low as $10^{-4}cm^2/s$. Continuous data collection for the transient measurement provides high precision as well as a monitor of experimental variability.

Comparison of transient-diffusion coefficients for radon with those from steady-state measurements on the same materials is important for two reasons. First, agreement between these two independent measurements provides a check on their theoretical validity and their technical accuracy. Second, the nature of the diffusion process can be examined in greater detail. Steady-state diffusion measurements yield an effective radon diffusion coefficient which includes the effects of all experimental variables and mechanisms, such as soil structrue and moisture effects, absorption and adsorption effects, temperature and pressure effects, and advective transport. The transient-diffusion measurements can potentially provide an extra degree of freedom in understanding the diffusion process by illustrating the effects of any parameters, such as absorption of radon by water, which may have very different time constants than the radon diffusion process.

I/3 H-3

The following sections compare the experimental parameters for transient and steady-state diffusion measurements, and describe the experimental details of sample preparation, data acquisition, system calibration, and data interpretation. The results of transient-diffusion measurements on natural soils are also presented and compared with steady-state measurements on the same soils. Transient measurements on several reference materials are also reported and discussed in terms of the precision and accuracy of the method.

PARAMETERS FOR RADON DIFFUSION MEASUREMENTS

Radon diffusion coefficients for homogeneous materials are usually measured by application of a radon concentration gradient across a sample and measurement of the resulting response in terms of steady-state radon flow, steady-state concentration gradients, or transient radon accumulation. For simplicity of interpretation, the experiments are designed so that one-dimensional diffusion equations are applicable, and occasionally, so that only one diffusion region needs to be considered. Although only the region defined by the sample is strictly of interest, it is often necessary to consider the air-filled source or detection regions at either end of the sample region to adequately interpret the experimental data.

Four main parameters can be measured in a radon diffusion experiment. Two of these four are generally adequate for the diffusion coefficient calculation. The four parameters are (a) the initial radon flux from the bare radon source, (b) the radon flux from the exit end of the sample column, (c) the radon concentration at the entrance end of the column and (d) the radon concentration at the exit end of the column.

Steady-state radon diffusion measurements have been conducted using parameters (a) and (b), parameters (a) and (c), and parameters (c) and (d). The

I/4 H-4

steady-state method used in the present comparisons with the transient technique utilized parameters (a) and (c). As indicated in References 4 and 5, the radon diffusion coefficient from these parameters can generally be determined from the one-region, one-dimensional equation

$$\frac{C_0}{J_0} = \frac{\tanh(k_s b)}{k_s D_e} \qquad (1)$$

where

C_0 = radon concentration in the pore space at the column entrance (parameter c) (pCi/cm^3)

J_0 = radon flux from bare source (parameter a) ($pCi/cm^2 s$)

k_s = $(\lambda P_s/D_e)^{1/2}$ (cm^{-1})

λ = radon decay constant ($2.1 \times 10^{-6}\ s^{-1}$)

P_s = soil porosity

D_e = effective diffusion coefficient of radon in the bulk soil (cm^2/s)

b = thickness of soil layer (cm)

Equation (1) differs slightly from those reported in References 4 and 5 due to the present definition of C_0.

For the steady-state measurements of low diffusion coefficients, the volume of the source region beneath the sample becomes important due to radon decay in the source region. For general steady-state diffusion measurements, Equation (1) should be replaced by the two-region, one-dimensional equation

$$\frac{C_0}{J_0} = \frac{\tanh(k_s b)}{k_s D_e \cosh(k_A a) + k_A D_A \sinh(k_A a) \tanh(k_s b)} \qquad (2)$$

where

k_A = $(\lambda/D_A)^{1/2}$ (cm^{-1})

~~I-5~~ H-5

D_A - diffusion coefficient of radon in air (cm^2/s)

a = thickness of the air-filled source region (cm)

A similar phenomenon occurs in the transient diffusion measurement system. In this case, parameters (c) and (d) are used to determine the diffusion coefficient, with parameter (d) being measured continuously with time. There are two other experimental differences between the present equilibrium and transient measurements. First, the radon source concentration is maintained constant in the transient system instead of the source radon flux being constant. Second, the radon concentration at the exit end of the column increases with time in the sealed detection chamber rather than being kept at approximately zero as in the steady-state measurements. Due to the different boundary conditions, the thickness of the air-filled detection chamber becomes significant in the transient system rather than the thickness of the source region as in the steady-state system. In both systems, the thickness of the sealed air-filled regions is only significant when the radon diffusion coefficient of the soil being tested is low ($D_e/P_s<10^{-3}cm^2/s$).

The basis for interpreting the transient radon diffusion data is the one-region, one-dimensional, time-dependent solution to the radon diffusion equation,

$$C(t) = C_0\sum_{n=1}^{\infty} \frac{(-1)^{n-1}(2n-1)}{\pi(2n-1)^2/4 + \lambda b^2/(\pi D)} \left\{ 1-\exp\left[-\lambda t-(2n-1)^2 \frac{\pi^2 D}{4b^2} t\right]\right\} \tag{3}$$

where

D = diffusion coefficient of radon in the soil pore fluid (cm^2/s) = D_e/P_s

t = time from radon source exposure to concentration measurement (s)

Since the transient-diffusion measurement system measures the alpha activity of the radon daughters ^{218}Po and ^{214}Po along with that of the radon, the

I/6 H-6

Bateman equations$^{(6)}$ were coupled with Eq (3) in a computer program to calculate total alpha activities. This provided for calculating the radon daughter ingrowth with time for the varying radon concentrations which also increased with time. The coupled equations were analyzed by computer to calculate the total alpha activity at any time as a function of soil column length and radon diffusion coefficient.

Since the two-region transient diffusion problem is very complicated and analytical solutions are not available, the one-region analytical solution in Eq (3) was used with two correction factors to account for the air-filled detection region. One of these factors was the ratio of the radon concentration from a steady-state, two-region soil and air problem (C_2) to that from a steady-state, one region soil problem (C_1), and was calculated as

$$\frac{C_2}{C_1} = \left[1 + \left(\frac{D_A}{P_s D_e} \right)^{\frac{1}{2}} \tanh(k_s b) \tanh(k_A a) \right]^{-1} \qquad (4)$$

This factor gave an exact correction for the final plateau region of the transient curves, and was multiplied by the source concentration in Eq (3). Its magnitude is near unity until diffusion coefficients of about 10^{-3}cm^2/s or less are attained, and it approaches a value of 0.5 as the soil diffusion coefficient approaches 10^{-5}cm^2/s. Since the correction is a constant multiplier of any given transient activity curve, it does not directly affect the estimation of diffusion coefficients. Instead, it acts as a change in the detector efficiency calibration, which can even be treated as a variable in fitting transient activity curves.

The second correction factor had a direct effect on the value of the radon diffusion coefficient, and accounted for multidimensional effects near the boundary between the soil region and the air-filled detection region. The

I-A H-7

decrease in radon accumulation rate in the detector region is related to the soil porosity, so that this correction is equivalent to using D_e in place of D in Eq (3). It should be noted that this correction was not applied to the transient-diffusion coefficients reported in Reference 7, so that those diffusion coefficients should be regarded as D_e. In the present work, the correction was applied so that the best fit to the measured data yielded the correct value of D.

EXPERIMENTAL METHOD FOR TRANSIENT MEASUREMENTS

Based on the foregoing time-dependent equations for radon diffusion, an experimental apparatus was designed to determine radon diffusion coefficients. The conceptual basis of the experimental measurements is as follows. A column containing the soil to be tested is exposed on one end at time zero to a large volume of air containing a known high radon concentration. A continuous alpha particle detector is sealed to the opposite end of the column to measure the alpha activity from radon and its daughters. As radon diffuses through the soil, the measured alpha activity increases to a constant maximum level which corresponds to an equilibrium radon distribution throughout the soil. The measured alpha activity buildup curve is then compared to theoretical curves calculated for various diffusion coefficients and the actual diffusion coefficient is inferred from the best fit. The following sections describe the experimental apparatus and procedure, the sample preparation procedure, the calibration procedure, and the data interpretation procedure.

Diffusion Apparatus

The experimental apparatus used for the transient radon diffusion measurements is illustrated in Figure 1. The radon source consisted of uranium mill

I/8 H-8

tailings obtained from the Vitro Tailings pile in Salt Lake City. These tailings have been found(7) to contain about 1450 pCi/g ^{226}Ra, and to have a radon emanation coefficient of about 0.22. Approximately 150 kg of the tailings were placed in a 220-liter steel drum with five perforated tubes to facilitate radon diffusion. The large air volume at the top of the drum was sufficient to maintain a constant concentration radon source throughout the experiment. A 10-cm gate valve was located at the top of the drum to contain the radon between measurements and to allow unrestricted access of the radon gas to the test column entrance. By only opening the gate valve with a sample column sealed in position, the radon concentration in the drum accumulated to a steady-state concentration of about 2.8 x 10^5pCi/L. A subsequent source was later utilized which reached 4 x 10^5pCi/L. A sampling port located at the top of the drum

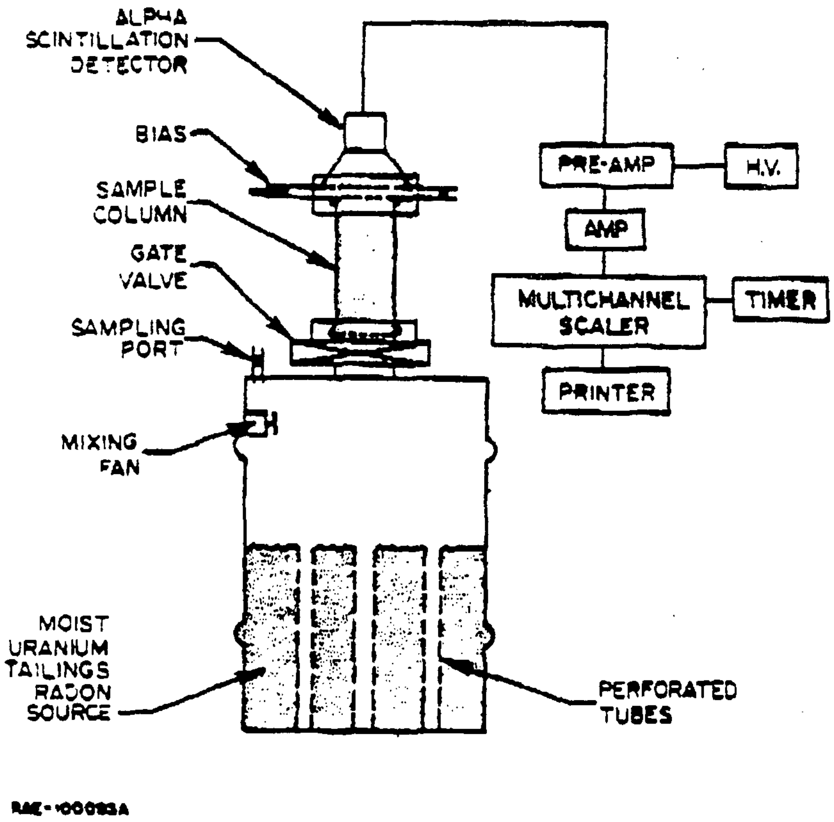

FIGURE 1. TIME-DEPENDENT RADON DIFFUSION APPARATUS

~~I9~~ H-9

facilitated sample collection for calibration purposes.

A double O-ring fitting was attached to the upper side of the gate valve for attachment of the sample column, which was made from SCH-80 PVC plastic pipe. A similar fitting was used on the detector assembly to provide a gas-tight seal to the sample column. The detector assembly consisted of a 10-cm diameter alpha scintillation detector, located 2.5-cm from a metal screen which rested on the top of the sample column. A 300-V negative bias was maintained on the detector face with respect to the screen to attract the positive radon daughters toward the detector as they were formed. A gas sampling port was also located in the detector assembly to allow collection of calibration samples.

The alpha scintillation detector was powered by a pre-amp/amplifier combination with adjustable threshold, discriminator, and gain setting. A scaler/timer and printer assembly provided continuous printouts of alpha activity over any selectable integration interval. Typical integration intervals were one, ten, or twenty minutes.

Sample Preparation and Measurement Procedure

Soil samples were prepared by first adjusting the moisture of the soil so the approximate desired level by addition of water or by permitting short drying periods. Once the water content was adjusted and equilibrated, the soil was packed into a 10-cm diameter PVC pipe in approximate 1-2 cm lifts. Packing was generally accomplished with a short metal rod, and the desired density could usually be attained in the first one or two attempts. Moist or highly compacted dry samples were self-supporting in the sample tube, but loose dry samples required a supporting screen at the bottom.

The compacted sample was then attached to the radon source and detector assemblies as illustrated in Figure 1. Background counts were then conducted

~~I-10~~ H-10

over approximately one hour, after which the diffusion experiment was started by opening the gate valve to the radon source. A small mixing fan located inside the source drum (Figure 1) was kept continually running, and served to quickly mix the air immediately beneath the sample column with that in the source drum. The data collection process was allowed to continue over the next 18-72 hours, after which the gate valve was closed, and the sample column was removed. The actual moisture and density of the soil sample were then determined by drying the entire sample at 105-110° C until constant weight was attained.

Calibration

In order to interpret the transient alpha activity curves from the diffusion measurements, radon concentrations were required as a function of time at both ends of the column. For the source concentration, simple Lucas-cell samples were collected and found to remain constant with time. The continuous alpha scintillation detector was calibrated by allowing the radon in the detection chamber to reach equilibrium and then relating the observed count rate to the radon concentration measured from a Lucas cell grab-sample (10 cm^3). The scintillation detector was found to have a total alpha detection efficiency of about 14 percent.

Individual efficiencies for radon gas and for ^{218}Po and ^{214}Po were also required to properly interpret the transient curves for cases of high diffusion coefficients. The individual efficiencies were determined by allowing a relatively high radon concentration to equilibrate in the detection chamber, and observing the decay rates as the chamber was opened and ventilated. The decay rates were monitored on a one-minute time scale, and clearly illustrated the radon gas contribution with an immediate drop in count rate as the chamber was ventilated. The contribution of the ^{214}Po daughter was determined from

I/11 H-11

the latter part of the decay curve (>25 min after ventilation) because the preceding nuclides had nearly all decayed by this time. The contribution of ^{218}Po was finally determined from the activity during the first ten minutes after correcting for the contribution of the ^{214}Po. The respective relative efficiencies determined in this manner for ^{222}Rn, ^{218}Po and ^{214}Po were 10 percent, 45 percent, and 45 percent, leading to corresponding absolute efficiencies of 4 percent, 19 percent, and 19 percent. The radon gas efficiency is lower than the daughter efficiencies because it is a volumetric source spread throughout the 2.5-cm thick detection chamber. The daughter efficiencies are higher because they are attracted by the 300-V bias to the detector surface, and therefore have a more favorable detection geometry.

Data Description and Analysis

The transient alpha activity curves which result from a diffusion experiment are characterized by an initial lag period, a transition or breakthrough region, and a final plateau region which corresponds to an equilibrium radon distribution. Figure 2 illustrates a family of characteristic alpha activity curves calculated for various diffusion coefficients for a 14.8-cm diffusion column. As illustrated, an empty, air-filled column having a diffusion coefficient of about 0.1 cm^2/s would break through almost immediately, and would reach equilibrium within a few hours. A soil with a diffusion coefficient of about $10^{-3} cm^2/s$ would only begin to break through after several hours, and would not reach equilibrium for more than a day. Materials with lower diffusion coefficients have even longer lag times, and reach plateaus at lower concentrations due to the significant decay which occurs in the sample column.

In order to provide greater flexibility in measuring a wide range of diffusion coefficients, the column length may also be varied. Longer columns are typically used for dry, porous materials with expected high diffusion

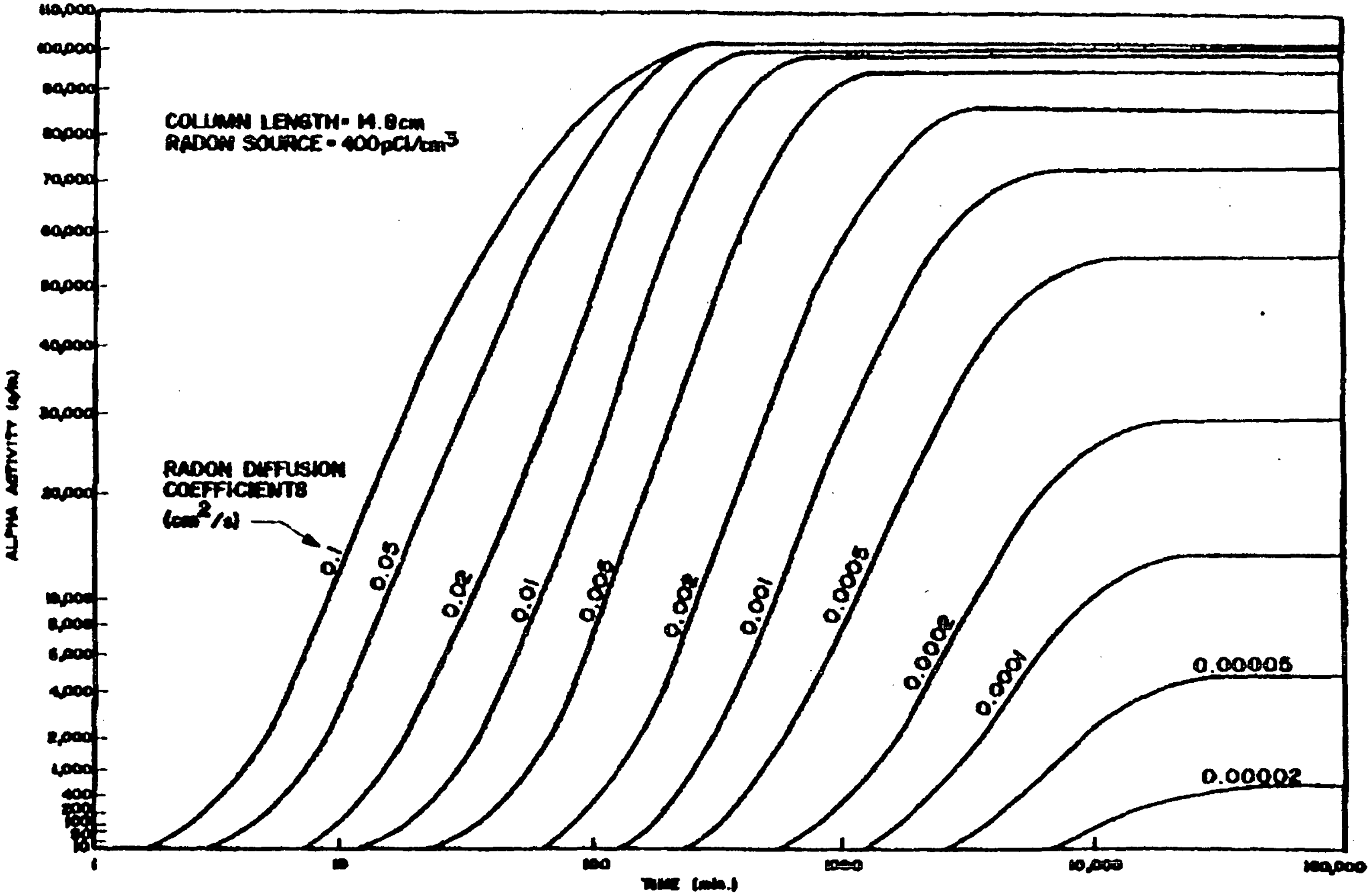

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FIGURE 2. TRANSIENT ALPHA ACTIVITY CURVES FOR VARIOUS DIFFUSION COEFFICIENTS

H-12

I/13 H-13

coefficients and shorter ones are used for moist, highly compacted clays. Figure 3 illustrates the predicted alpha curves for columns of varying lengths and with a constant diffusion coefficient of $10^{-3}cm^2/s$.

Experimental data were analyzed by a computer program which calculated the transient alpha activity curves as illustrated in Figures 2 and 3 using Eq (3) and (4) and the Bateman equations. The program utilized ten alpha activity data points spread primarily throughout the transition or breakthrough region of the curves, and determined by least-squares fit the diffusion coefficient which best fit the measured alpha activity data. The estimate of uncertainty in the diffusion coefficient was obtained as the standard deviation of ten diffusion coefficients determined from pairs of adjacent points taken from each of the ten locations on the curve used in the least-square fit. Typical relative standard deviations of the radon diffusion coefficients were calculated to be on the order of 5-12 percent.

RESULTS AND DISCUSSION

The transient-diffusion measurement technique was applied to several soil materials which had been previously analyzed by the steady-state diffusion measurement method.(5) It was also used to measure the radon diffusion coefficient of air and of selected other reference materials whose diffusion coefficients were known. The following sections describe the results of the comparative soil measurements and the standard reference measurements.

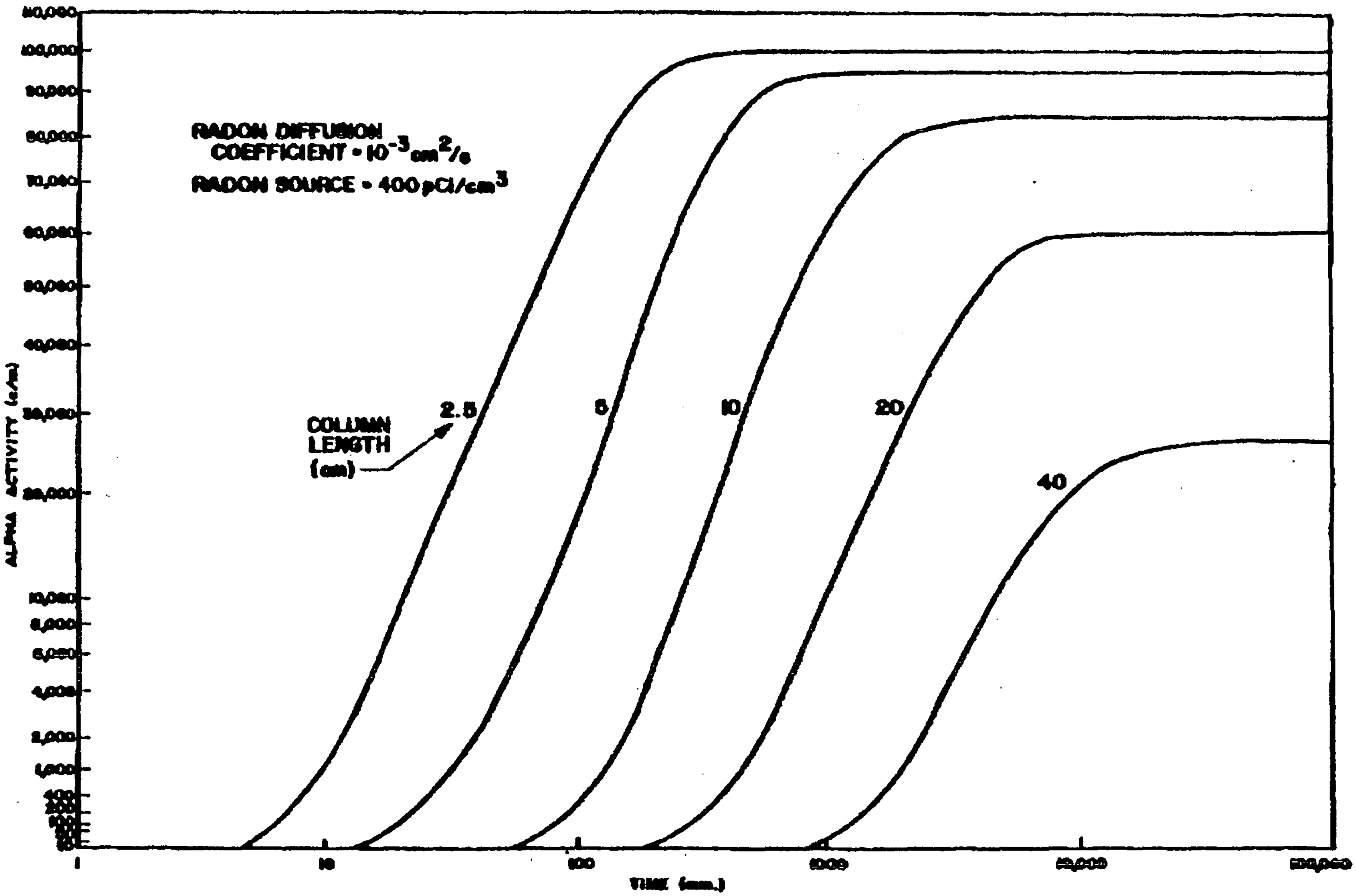

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FIGURE 3. TRANSIENT ALPHA ACTIVITY FOR VARIOUS COLUMN LENGTHS

H-14

T-14

Radon Diffusion Through Soils

Transient radon diffusion measurements were conducted on five different soils at a variety of different moisture contents. The results of these diffusion measurements are summarized in Table I in terms of the soil porosity, its moisture content (volume fraction of saturation), and the radon diffusion coefficient. As indicated by the porosities, the compactions were held relatively constant for each soil, while the moisture contents were varied for the different diffusion measurements. As indicated, the diffusion coefficients generally decreased with increasing moisture content, as was expected from theoretical considerations(8) and from previous experimental work and empirical correlations.(2,3,9) Two exceptions to this trend are noted in Table I for the D clay and M shale materials at their highest moisture contents. The increases in these two diffusion coefficients were relatively small, and were attributed to the high variability in the value of the moisture content that occurs in preparing wet samples. Some of the uncertainty could also be associated with the value of the best fit diffusion coefficient to the data points.

Comparative steady-state radon diffusion measurements(5) on the same soils are also listed in Table I. These data are part of a larger group of diffusion measurements conducted at PNL at varying soil moistures and compactions. Although the soil moistures and compactions used for the two types of diffusion measurements are not identical, they are sufficiently close to provide a valid comparison of results for many of the diffusion measurements. The ratios of coefficients from the two types of diffusion measurement indicate that the agreement between the two methods is within about 10 to 20 percent relative error for dry or relatively low-moisture soils (<20 percent saturation). The relative standard deviation among the five replicate transient diffusion measurements on dry dunite is 12 percent, suggesting that differences between the two methods for dry samples can largely be attributed to inherent uncertainties in the measurement procedure.

TABLE I

COMPARISON OF RADON DIFFUSION COEFFICIENTS FROM TRANSIENT-DIFFUSION AND STEADY-STATE MEASUREMENTS

	TRANSIENT-DIFFUSION			STEADY-STATE			
SAMPLE	Porosity	Sat'n.	D (cm^2/s)	Porosity	Sat'n.	D (cm^2/s)	D Ratio* Trans/S.S.
D Clay	0.42	0.10	0.045				
	0.41	0.15	0.017	0.39	0.15	0.016	1.0
	0.43	0.25	0.0070				
	0.40	0.35	0.011				
DF Sand	0.41	0.23	0.045	0.36	0.05	0.030	1.4
WN Clay	0.38	0.54	0.011	0.39	0.22	0.024	0.4
	0.38	0.86	0.0012	0.37	0.67	0.00051	2.2
M Shale	0.34	0.55	0.020	0.33	0.54	0.022	0.8
	0.30	0.86	0.0013	0.28	0.67	0.0013	0.9
	0.30	0.88	0.0022				
Dunite	0.46	0.00	0.050				0.8
	0.45	0.00	0.056				0.9
	0.45	0.00	0.066	0.44	0.00	0.06	1.0
	0.45	0.00	0.068				1.0
	0.45	0.00	0.064				1.0
	0.41	0.41	0.014				
	0.40	0.56	0.0030				

*Ratios multiplied by 0.915 to correct for the atmospheric pressure difference between RAE (1286m elevation) and PNL (110m elevation).

~~I-17~~ H-17

Comparisons of the diffusion coefficients at higher moistures are more complicated. As shown in Table I, good agreement between the two methods was observed for M shale, despite significant moisture differences in one of the comparisons. For DF sand and WN clay, however, the diffusion coefficients differed by factors of 0.4 to 2.2. The diffusion through DF sand was measured at a much higher moisture in the transient case, which should have caused a lower diffusion coefficient, despite the partially compensating effect of the higher porosity with the transient measurement. The transient-diffusion measurements on WN clay showed a reasonably lower diffusion coefficient for the higher moisture content in the first case. However, the second case showed a 2.2-times higher diffusion coefficient in the presence of a slightly higher moisture content.

A likely reason for the higher D ratios at high moisture contents is in the technique used for the equilibrium diffusion measurements. Soil samples for these measurements were prepared with initially high moistures, and were used to determine diffusion coefficients at various lower moistures by allowing evaporation from the top surface of the soil column. The resulting moisture distributions were therefore non-uniform in the direction of diffusion and gave the effect of a lower diffusion coefficient than would occur if the measured moisture were uniformly distributed throughout the soil. Although the data did not permit a quantitative measure of this effect for each sample, it easily could have had sufficient magnitude to explain the high D ratios in Table I. Therefore, the reliability of the steady-state measurements is in question at high moistures.

Another cause of variation among the D-ratios at high moistures in Table I is the random error associated with packing homogeneous moist soils into the diffusion columns. This random error results from non-uniform moisture distributions, non-uniform compaction of the soils into the columns, and varying degrees of consolodation of the original soil crumbs being compacted. These

~~I-18~~ H-18

variations could affect both the transient and the steady-state measurements, and would cause decreased diffusion rates if they occurred in the direction of diffusion and enhanced rates if they occurred perpendicular to the direction of diffusion. The overall effect of soil or moisture inhomogeneity was thus an increase in the uncertainty of the diffusion measurements. Since moisture is a dominant parameter, the samples with high moisture contents tended to exhibit higher uncertainties in diffusion coefficients.

Evidence of radon absorption by the moisture in the soil was sometimes observed in the transient alpha activity curves. This phenomenon was usually expressed as a more gradual slope in the breakthrough region of the transient curves, and was readily detected by plotting the measured activity curve with the family of calculated curves for the given column length and source strength as shown in Figure 2. Ideally, the measured curve was parallel to the adjacent calculated curves. However, at high moistures, the measured curve sometimes crossed several of the calculated curves because of the time dependence of the moisture absorption and related effects. This phenomenon was usually minimized by using shorter diffusion columns. It was also generally possible to use the upper part of the breakthrough region of the curve to calculate the diffusion coefficient, as this region generally remained parallel to the expected curve shapes. The transient diffusion data were routinely plotted with the calculated curves as a check for systematic errors before computing diffusion coefficients.

Reference Diffusion Measurements

In order to further verify the accuracy of the transient-diffusion measurement technique, several diffusion measurements were conducted in dry air and certain other well-defined media. These diffusion measurements allowed comparison with theoretically-derived diffusion coefficients as well as with other measurement techniques, and avoided the uncertainties associated with soil structures and moisture distributions. Table II summarizes these diffusion measurements. As indicated, a nine percent correction was applied to compensate for the elevation and resultant reduced pressure at the RAE laboratory.

The diffusion coefficients for dry air utilized an empty soil sample tube in the transient-diffusion apparatus. As in the measurements with soils, coarse filter papers, with porosities exceeding 0.9, were placed at the entrance and exit of the tube to avoid turbulence from the mixing fan in the radon source chamber and to define the tube boundary. The resulting diffusion coefficients in Table II are in excellent agreement with the theoretical diffusion coefficient predicted for radon in air from the Othmer-Chen equation,(3,10) 0.105 cm^2/s. Good agreement is also noted with the experimental measurements referenced by Tanner,(11) which ranged from 0.10-0.12 cm^2/s.

In a subsequent experiment, the sample tube was packed with parallel wooden dowels. This provided a porosity of 0.25 in the diffusion tube, and a simple pore structure without tortuosity. Because of the much smaller size of the pores within the wood and the blockages caused by its cellulose structure, the porosity of the dowels was neglected. As indicated, the resulting diffusion coefficient was within experimental error of the values for dry air. Although the observed value may be slightly high due to the wood porosity, the magnitude of the bias is not significant.

Three additional measurements were conducted in which uniform glass balls and differential sieve fractions of dry sand were used as the diffusion medium. In these cases, the tortuosity was obviously not unity, and a lower value of D was expected. The measured D values verify that the diffusion coefficient for a straight air pathway was significantly lowered by the granular nature of these samples. If the standard D values in Table II are divided by the estimated tortuosities of these samples, the results should be comparable to the diffusion coefficient of air. Using the spherical-particle approximation reported

TABLE II

TRANSIENT-DIFFUSION MEASUREMENTS ON STANDARD REFERENCE MATERIALS

SAMPLE	POROSITY	MEASURED D (cm^2/s)[a]	STANDARD D (cm^2/s)[b]
Air	1	0.110	0.100
Air	1	0.120	0.109
1-cm diameter wood cylinders	0.25	0.124	0.113
4-mm diameter glass balls	0.33	0.078	0.071
Dry sand 16-30 mesh	0.47	0.060	0.054
Dry Sand 50-100 mesh	0.46	0.063	0.057

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[a] Measured at 1286m elevation, 0.908 atm. pressure.

[b] Multiply measured D's by 0.908 to convert to Standard D at 1-atm pressure (sea-level).

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previously[8] for estimating tortuosities, the glass ball, coarse sand and fine sand samples were estimated to have respective tortuosities of 0.68, 0.66 and 0.66. Normalizing the respective standard diffusion coefficients from Table II by these tortuosities gives radon diffusion coefficients of 0.104, 0.082 and 0.086 cm^2/s. The glass ball measurement is thus in excellent agreement with the expected value for radon in air, and the 20-25 percent relative errors in the normalized sand measurements could well be a result of the influence of the non-spherical sand grain shapes on the tortuosity estimate. The standard diffusion coefficients reported for the sieved sand fractions are thus reasonable despite being slightly lower than the glass ball sample. In all three granular samples, pore sizes were sufficiently large for diffusion to be in the molecular regime, and not in the Knudsen or transitional regimes.

Precision and Accuracy

The precision of the transient radon diffusion measurement technique was directly evaluated by the five replicate measurements on the dry dunite reported in Table I. The relative standard deviation among these diffusion coefficients was 12 percent (0.0608 ± 0.0076 cm^2/s). This precision is probably representative of the uncertainties in the measurement process, since the dunite sample was dry and could readily be poured into a reproducible packing configuration and density.

The higher uncertainty associated with radon diffusion measurements through moist soil samples cannot be directly deduced from only the present measurements. This uncertainty was estimated from previous transient-diffusion measurements that were made on duplicate samples of moist clay-type soils. Moistures ranged from 50 to 100 percent saturation and moistures of the duplicate samples were within 1.0 wt percent of each other. In addition, the corresponding compactions were nearly identical. Using a one-way analysis of variance on the log-transformed diffusion coefficients, the geometric standard deviation among the replicate analyses was estimated to be 1.43.

In evaluating the sources of random error in transient-diffusion measurements, uncertainties from alpha counting statistics and from the count timing sequence are minimal. The predominant components of the 12 percent relative variation observed for the dunite appear to be pressure and temperature variations and sample packing variations. Although the diffusion measurement system is sealed throughout the course of a diffusion measurement, the varying atmospheric pressures at the times of sample insertion could account for some of the observed variation. Random errors in excess of the 12 percent level are attributed to variations in sample characteristics.

The accuracy of the transient radon diffusion measurement technique was primarily evaluated from the diffusion coefficients in air and other well-defined materials in Table II. The variation of these coefficients from the theoretical value of 0.105 cm^2/s is much smaller than the uncertainty associated with the precision of the method (12 percent). No significant bias was thus observed in these measurements.

In comparing the transient diffusion coefficients with the equilibrium measurements at PNL, the transient data fell within 10 to 20 percent of the equilibrium data for all but the three comparisons which involved extremely different soil moistures. The moisture differences, moisture gradients (in equilibrium measurements), and sample preparation uncertainties adequately account for these larger differences. The overall comparison of the two methods in Table I indicates very good agreement. The average ratio of all of the transient/equilibrium comparisons was 1.04.

It should be noted that both atmospheric pressures and laboratory temperatures can affect radon diffusion coefficients. The diffusion coefficients are inversely proportional to atmospheric pressure,(10) and thus require a correction due to altitude differences when comparisons are made for different locations. These corrections have been implemented in Tables I and II, and amount to about nine percent in correcting for the 1286m elevation of the RAE laboratory to 1-atm sea level conditions. The temperature correction is ordinarily smaller, and was not applied to the present measurements. The transient-diffusion coefficients were measured at laboratory temperatures ranging from 19-23°C. Temperature effects on diffusion coefficients have been estimated(3) to amount to 0.8 percent/°C, suggesting a three percent variation among the present measurements due to temperature differences. The temperature effects are thus small compared to diffusion measurement precisions. The calculated radon diffusion coefficient for air(3) was based on a temperature of 25°C.

CONCLUSIONS

The measurement of radon gas diffusion coefficients under transient conditions provides a rapid and accurate alternative to traditional steady-state diffusion measurement techniques. Radon diffusion coefficients measured by the transient method show excellent agreement with the theoretically calculated diffusion coefficient for air as well as with previously measured coefficients for air. Measured diffusion coefficients also agreed with theoretical expectations for diffusion through a column packed with glass balls.

Comparative measurements on compacted soils also showed good agreement with steady-state diffusion measurements. The agreement was best at low moistures, where relative differences averaged less than ten percent. At high moistures, the relative differences amounted to approximately a factor of two, although a significant part of this difference was attributed to non-uniform moisture in the steady-state measurements. Since the transient and steady-state diffusion measurements utilized completely different experimental conditions, measurement methods, and mathematical interpretations, the comparisons give an excellent verification of the theoretical and technical accuracy of both approaches.

Precisions were estimated from five replicate transient diffusion measurements with dry dunite. A relative standard deviation of 12 percent was observed. An estimate of the precision at soil moistures from 50 to 100 percent of saturation yielded a relative uncertainty for the moist soils that was about three to four times greater than that for the dry samples.

The transient-diffusion measurement technique utilizes small samples, facilitating greater control over sample characteristics. Since these appear to dominate experimental uncertainties, good precisions are attainable. The transient method also offers significantly shorter measurement times than steady-state methods.

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APPENDIX

DERIVATION OF RADON DIFFUSION EQUATIONS

DERIVATION OF RADON DIFFUSION EQUATIONS

Equation 1

Equation (1) was derived from the one-dimensional, steady-state diffusion equation without radon sources,

$$D \frac{\partial^2 C}{\partial x^2} - \lambda C = 0. \tag{A1}$$

The general solution to equation (A1) is

$$C_s(x) = E \exp(k_s x) + F \exp(-k_s x), \tag{A2}$$

where E and F are constants to be determined by the boundary conditions of the system and the subscript s refers to the soil medium in which the diffusion occurs. From Fick's law, the radon flux for the system is

$$J_s(x) = - D_e \frac{\partial C_s}{\partial x} = D_e k_s \left[-E \exp(k_s x) + F \exp(-k_s x)\right], \tag{A3}$$

and the boundary conditions imposed on this one-region problem are

$$J_s(0) = J_0 \tag{A4}$$

and

$$C_s(b) = 0, \tag{A5}$$

where J_0 is the radon flux entering the soil at the source end (x=0) and $C_s(b) = 0$ is the negligible radon concentration at the exit end (x=b) of the system. Substituting the boundary conditions (A4) and (A5) into Equations (A2) and (A3), and defining the source concentration $C_0 = C_s(0)$, the ratio for C_0/J_0 is found to be

$$\frac{C_0}{J_0} = \frac{\tanh(k_s b)}{D_e\, k_s} \qquad \text{(A6)}$$

Equation 2

Equation (2) was also based on the one-dimensional, steady-state diffusion equation (A1), for which equation (A2) was defined to be the solution applying to the soil region. A second solution, applying to the air-filled source region, was also written as

$$C_A(x) = G\exp(k_A x) + H\exp(-k_A x), \qquad \text{(A7)}$$

where the constants G and H are additional constants to be determined by the boundary conditions of the system. The radon flux defined by Fick's Law for the soil region is still given by equation (A3), and the corresponding equation for the flux in the air-filled source region was written as

$$J_A(x) = -D_A\frac{\partial C_A}{\partial x} = D_A k_A\left[-G\exp(k_A x) + H\exp(-k_A x)\right] \qquad \text{(A8)}$$

Four boundary conditions were defined for the two-region system, which was defined to have its origin at the soil-air interface, and which had a soil thickness of b and an air thickness of a. The boundary conditions were

$$J_A(-a) = J_0 \qquad \text{(A9)}$$
$$J_A(0) = J_s(0) \qquad \text{(A10)}$$
$$C_A(0) = C_s(0) \qquad \text{(A11)}$$
$$C_s(b) = 0 \qquad \text{(A12)}$$

Applying the boundary conditions (A9-A12) to Equations (A2), (A3), (A7) and (A8), the constants E, F, G and H were determined, from which the ratio C_o/J_o was determined to be

$$\frac{C_o}{J_o} = \frac{\tanh\,(k_s b)}{D_e k_s \cosh(k_A a) + D_A k_A \sinh(k_A a)\,\tanh\,(k_s b)} \tag{A13}$$

Again, the definition $C_o = C_A(0) = C_s(0)$ was used.

Equation 3

The derivation of Equation (A3) for a single region comes from the one-dimensional, time-dependent diffusion equation

$$D\,\frac{\partial^2 C}{\partial x^2} - \lambda C = \frac{\partial C}{\partial t}\,. \tag{A14}$$

Defining the origin as the source end of the diffusion column, the following three boundary conditions were employed:

$C(x,0) = 0$ (no initial radon) (A15)

$C(0,t) = C_o$ (constant source concentration) (A16)

$\left.\frac{\partial C}{\partial x}\right|_{\substack{x = b \\ \text{all } t}} = 0$ (no leakage at detector end) (A17)

Taking the Laplace transform of Equation (A14) with respect to t, and applying the boundary condition from Equation (A15),

$$D\,\frac{d^2\bar{C}}{dx^2} - \lambda\bar{C} = S\bar{C} \tag{A18}$$

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The boundary condition in Equation (A16) now becomes

$$\bar{C}\ (0,S) = C_o/S \tag{A19}$$

and that in Equation (A17) becomes

$$\left.\frac{d\bar{C}}{dx}\right|_{x\ =\ b} = 0 \tag{A20}$$

Defining $\alpha^2 = (S + \lambda)/D$, the solution to Equation (A18) is

$$\bar{C}\ = A\ \exp(-\alpha x) + B\ \exp\ (\alpha x) \tag{A21}$$

Applying the boundary conditions, the constants A and B are determined and the resulting solution for $\bar{C}$ is inverted and integrated to express the solution for $C(x,t)$ at the point $x = b$ as

$$C(b,t) = C_o \sum_{n=1}^{\infty} \frac{(-1)^{n-1}\ (2n-1)}{\pi(2n-1)^2/4 + \lambda b^2/(\pi D)} \left\{1 - \exp\left[-\lambda t-(2n-1)^2 \frac{\pi^2 D}{4b^2}\ t\right]\right\}. \tag{A22}$$

Equation 4

The derivation of Equation (4) is based on a two-region solution of the one-dimensional, steady-state radon diffusion equation. The diffusion system being described is that of a steady-state radon distribution in a soil, one end of which is attached to a source of constant radon concentration, and the other end of which is sealed. An air gap is assumed between the soil and the sealed end of the column in the two-region case, and the thickness of the air region is set equal to zero for the one-region case. Equation (4) is simply the ratio between the radon concentrations at the sealed end in the two cases.

The general steady-state Equation (A1) is used, along with its solutions for the soil and air regions, Equations (A2) and (A7). The prior definitions of radon flux from Fick's Law for the soil and air regions are also used, as given in Equations (A3) and (A8). The system is defined to have its origin at the interface, with the air region extending to +a and the soil extending to -b. The four boundary conditions are

$$C_s(-b) = C_o \tag{A23}$$

$$J_s(0) = J_A(0) \tag{A24}$$

$$C_s(0) = C_A(0) \tag{A25}$$

$$J_A(a) = 0 \tag{A26}$$

Applying the boundary conditions, solving for E, F, G, and H, and letting $C_2 = C_s(0)$,

$$C_2 = C_o \frac{D_e k_s}{D_e k_s \cosh(k_s b) + D_A k_A \tanh(k_A a) \sinh(k_s b)} \tag{A27}$$

For the one-region case, Equation (A2) can be similarly defined by letting $C_1 = C_s(0)$, $a = 0$, and simplifying to get

$$C_1 = \frac{C_o}{\cosh(k_s b)} \tag{A28}$$

The ratio of the concentration for the two-region case to that for the one-region case is therefore obtained by dividing Equation (A27) by Equation (A28) and simplifying with the definitions of k_s and k_A to obtain

$$C_2/C_1 = \left[1 + \left(\frac{D_A}{P_s D_e}\right)^{1/2} \tanh(k_s b) \tanh(k_A a)\right]^{-1} \tag{A29}$$

APPENDIX I

RADIOLOGICAL SURVEY REVIEW

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
REGION IV
URANIUM RECOVERY FIELD OFFICE
BOX 25325
DENVER, COLORADO 80225

DEC 20 1991

URFO:DLJ
Docket No. 40-1162
04001162220R

Western Nuclear, Inc.
ATTN: Stephanie Baker
200 Union Blvd., Suite 300
Lakewood, Colorado 80228

Dear Ms. Baker:

NRC has reviewed your letter dated December 12, 1991, requesting evaluation of the proposed activity of borrow material for the reclamation cover design. The proposed value of 1.1 pCi/g is acceptable. However, due to the anomalies in the data that were presented to support this activity, a gamma survey should be performed during construction to ensure that material with activities greater than the agreed upon background are not placed in the cover system. Unless notified otherwise, NRC will assume that the gamma survey program will be included in the revised reclamation plan that you are currently preparing.

If you have any questions, please contact Dawn L. Jacoby of my staff on (303) 231-5815.

Sincerely,

Ramon E Hall

Ramon E. Hall
Director

cc:
R. Collins, WNI
J. Hough, RCPD, WY
WDEQ (2)

I-2

WESTERN NUCLEAR, INC.

UNION PLAZA SUITE 300. 200 UNION BOULEVARD. LAKEWOOD. COLORADO 80228
TELECOPIER (303) 989-8993 TELEPHONE (303) 989-8675

December 12, 1991

Mr. Ramon Hall, Director
Uranium Recovery Field Office
U.S. Nuclear Regulatory Commission
P.O. Box 25325
Denver, CO 80225

RE: DOCKET NO. 40-1162, SUA-56, 14 MAY 1991 NRC LETTER, COMMENT NOS. 37 & 38

Dear Mr. Hall:

On 11 December 1991, I met with your staff, Messrs. Hawkins and Ward and Ms. Jacoby, to try to discuss what value for radium-226 in borrow areas previously impacted by windblown tailings could be used for purposes of radon barrier calculations. In other words, in areas previously impacted by windblown tailings, while concentrations of radium in land might comply with Criterion 6, Appendix A to 10 CFR 40, for release to unrestricted areas, any potential excess radium above background in tailings cover material borrow areas would have to be accounted for as a source term in radon barrier calculations.

1987 COMPREHENSIVE RADIOLOGICAL SURVEY AT SPLIT ROCK MILLSITE

For reference, in 1987, a comprehensive radiological survey was performed at the Split Rock millsite [see our transmittal to you dated 01 March 1988 of Revision No. 1 to the June 1987 Western Nuclear, Inc. (WNI) Jeffrey City Tailings Reclamation Plan]. Results of an external gamma radiation survey were correlated with radium-226 concentrations to a depth of 0-6 inches. Further, radium-226 and uranium analyses were performed on soil samples collected to a depth of 0-6 feet in both undisturbed [background] and disturbed [areas impacted by windblown tailings] areas. Areas surveyed and sampled are depicted on figures accompanying our 01 March 1988 submittal. For the 1987 survey, the sample population mean for background Area 1 appears to have been determined from soil samples at 0-6 inches in depth.

For purposes of tailings cover borrow evaluation, Areas 5, 6 [excluding sample site 6-2 which is situated within the final tailings reclamation cap] and 7 contain designated tailings soil cover borrow areas. Area 1 represents the undisturbed background area. All other areas [2, 3 and 4] lie within the final tailings reclamation cap. Although area 8 lies outside the reclamation cap, Area 8 lies outside the area in the Northeast valley delineated for

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tailings cover borrowing.

In disturbed areas, it is my understanding samples at depth were taken based on a finding of elevated external gamma readings; therefore, soil samples in Area 7 are clustered together rather than randomly spread throughout all of Area 7. As we discussed in our 11 December meeting, while the sampling pattern may not be considered appropriate for purposes of geotechnical considerations, the sampling was appropriate for purposes of radiological considerations. The 1987 soil sampling, then, would still be considered representative of the "worst case" radium in soil concentrations for all borrow areas.

RADIOLOGICAL CHARACTERIZATION OF BORROW AREAS FOR RADON BARRIER CALCULATIONS

Recent conversations with Mr. Hawkins of your staff yielded the suggestion that the 1987 radiological survey data be used to calculate both an arithmetic average and a standard deviation of radium in soil samples from depths of 0.5-6 feet in proposed tailings soil cover borrow areas. This sample population mean plus three standard deviations would then define an upper bound for "background" for radium in soil for purposes of evaluating potential radium contamination at depth in tailings cover borrow areas.

If any radium values at 0.5-6 feet in depth were to exceed background, then all radium values at depth would be averaged to provide a "worst case" radium value. This average value would then be adjusted to accomodate for the radium concentration in excess of background, and the adjusted value could be used in radon barrier calculations. Enclosed herewith are the raw data from the 1987 radiological survey as well as a re-evaluation of pertinent 1987 data by an independent consultant [see 11 December 1991 letter from Dr. L. Hersloff, Radiant Energy Management, to S. J. Baker, WNI; copy enclosed herewith] for purposes of complying with the preceding.

The results of the re-evaluation of 1987 radiological data reveal an arithmetic mean and standard deviation of 1.4 and 0.8 pCi/g, respectively, as being representative of radium concentrations in undisturbed [by windblown tailings] Area 1. The mean plus three standard deviations that would represent "background", then, is 3.4 pCi/g.

A comparison of radium in soils in Areas 5, 6 and 7 reveal there are nine sample depths [n=103] below the 0-6 inch layer that exceed

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"background" of 3.4 pCi/g. The average of all radium in soil values at 0.5-6 foot depths below the surficial 6-inch windblown tailings layer is 2.5 pCi/g. The difference between the arithmetic means in Areas 5, 6 and 7 and Area 1 is 1.1 pCi/g. We therefore proposed a value of 1.1 pCi Ra-226/g be used as a representative "worst case" value for a radium source term in radon barrier calculations for all tailings cover soils.

Based on our 11 December meeting, however, it is my understanding the preceding procedure, although considered at the least to be representative of all borrow soils, is not acceptable in that the 1.1 pCi/g radium value contains no "conservatisms". An acceptable level of conservatism to your staff would translate into a value of 2.0 pCi/g. This value is derived from the difference between the upper bound of Area 1 "background" or 3.4 pCi/g and the arithmetic mean of 1.4 pCi/g. The 2.0 pCi/g value would then be used as the radium source term in radon barrier calculations.

JEFFREY CITY CONSTRUCTION ACTIVITIES TO DATE AND IMPACT ON TAILINGS COVER BORROW AREAS

Via letter dated 15 March 1991, we transmitted to you copies of the WNI "Split Rock Mill Tailings Regrading and Interim Cover Report (February 1991)". This report reveals that construction activities to date have resulted in soil excavation from the Northwest and Northeast borrow areas as summarized below:

Northwest borrow:

a. 0-6 inches windblown tailings returned to within the reclamation cap
b. topsoil salvaged from a depth of 12-26 inches below the windblown tailings
c. an average of 2.5 to 3 feet of soil has been excavated for placement of an interim soil cover; and in certain regions of the borrow area, in excess of 6 feet of soil has been removed for for interim soil cover placement

In summary, a minimum of 4 feet of materials have been excavated from the Northwest borrow area to date. In certain areas, in excess of 6 feet have been excavated. For reference, the 1987 radiological survey sampled only to a depth of 6 feet.

Northeast borrow:

a. 0-4.5 feet of windblown tailings returened to within the reclamation cap

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b. topsoil salvaged from a depth of 1.5 feet below the windblown tailings

c. approximately 200,000 CY of soil [approximately 3 feet average depth of excavation over 45 acres] are currently being excavated for purposes of completing the placement of an interim cover over all tailings areas

In summary, a minimum of 2 feet of materials have been excavated from the Northeast borrow area to date. Following completion of the interim cover over all exposed tailings, the minimum depth will have reached approximately 5 feet.

In response to your 14 May 1991 letter, we are currently striving to resolve a value for radium in cover soils that could be used in radon barrier calculations. It is my position that a value of 1.1 pCi radium-226/g is not only a concentration representative of radium in <u>all</u> tailings cover borrow soils, but is also conservative in that the value would be used for <u>all</u> tailings cover borrow soils.

It is my understanding that your staff believes this 1.1 pCi/g value to be representative but not conservative. Your staff is therefore considering a value of 2.0 pCi radium-226/g to provide the additional conservatism they deem necessary for purposes of radon barrier design.

It is also my understanding that your staff need some time to review the information contained herein before this issue can be resolved. It is also my understanding that your staff can complete the necessary review by early next week so WNI can complete its response to your 14 May letter and subsequently revise the Jeffrey City tailings reclamation plan. Therefore, if there is anything further that we can provide you to facilitate your review, please contact me at your earliest convenience.

Sincerely,

Stephanie J. Baker
Manager of Environmental Services
SJB/tic
cc: RWC
TAK
MAP
D. Kurz, Canonie

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REM

RADIANT ENERGY MANAGEMENT
LYDA W. HERSLOFF, Ph.D.
Health Physicist

December 11, 1991

Ms. Stephanie Baker
Western Nuclear
Union Plaza Suite #300
200 Union Blvd
Lakewood, CO 80228

Dear Stephanie,

I have reviewed the soil data collected during the 1987 radiological survey at the Split Rock Uranium mill site, Jeffrey City, Wyoming for Areas 1, 5, 6, and 7. Area 1 is designated the background area. Areas 5, 6, and 7 represent borrow areas for final soil cover.

In Area 1, a total of nine samples were collected to a depth of 6 feet at each of five sites, the five sites being representative of the range of gamma exposure readings in Area 1. The mean Radium-226 (Ra-226) concentration was determined to be 1.4 pCi/g with a sample standard deviation of 0.8 pCi/g. The mean Ra-226 concentration of 1.4 plus three standard deviations is equivalent to 3.4 pCi/g. The average gamma exposure rate in Area 1 was 16 ± 1.2 μR/hr (1988 report). Using the regression equations developed in the January, 1988 report, the predicted uncorrected gamma exposure rate for 1.4 pCi/g is 23 μR/hr, whereas the predicted corrected gamma exposure rate is 14 μR/hr.

In Area 5, there were 6 samples which exceeded the above value of 3.4 pCi/g including 5-1-1, 5-3-1, 5-4-1, 5-4-2, 5-4-6, and 5-4-8. In reading these sample numbers, the first number refers to the area, the second number to the location in the area and the third number to the sample depth. For example, 5-1-1 refers to Area 5, first location, surface interval 0-6" where the third numbers of 8 and 9 refer to composite samples of 4 to 5' and 5 to 6' respectively. As in Area 1, the soil sample locations in Areas 5, 6, and 7 represented the range of external gamma readings in each area. The mean value for all 29 samples collected to a depth of 6 feet in Area 5 was 9.84 ± 28.27 pCi/g. However, since the top 6" of soil from Areas 5, 6, and 7 were designated windblown tails based on the 1987 survey and were removed to the tailings pond, evaluation

10854 DIANE DR. GOLDEN, Co. 80403 (303) 642-7530

of the soil samples at depth below the surface 6" indicated a mean Ra-226 concentration of 2.3 ± 1.9 pCi/g in Area 5.

In Area 6, there were also 6 samples which exceeded the above value of 3.4 pCi/g including 6-1-1, 6-1-3, 6-1-9, 6-3-1, 6-4-1, and 6-4-2. The mean value for all 27 samples collected to a depth of 6 feet in Area 6 was 6.1 ± 12.3 pCi/g. As per above, excluding the samples in the top 6" of soil, the mean Ra-226 concentration is 5.1 ± 12.4 pCi/g.

In Area 7, there were 7 samples which exceeded the above value of 3.4 pCi/g including 7-1-1, 7-2-1, 7-3-1, 7-5-1, 7-6-1, and 7-6-5. The mean value the 63 samples collected to a depth of 6 feet in Area 7 was 3.1 ± 7.1 pCi/g. Again excluding the sample values in the top 6" of soil, the mean Ra-226 concentration at depths greater than 6" is 1.4 ± 1.6 pCi/g.

Evaluating all the soil data together, excluding the samples from 0-6" which have been removed as windblown tailings, the mean Ra-226 concentration is 2.5 ± 6.3 pCi/g based on 103 samples. The average Ra-226 concentration of 2.5 is 1.1 pCi/g above the average background concentration of 1.4 pCi/g and is within the 95% confidence interval of 1.96σ (1.6 pCi/g) associated with the background in Area 1. Further, the standard deviation of 6.3 pCi/g, is within the regulation for surface concentration for Ra-226 of 5 pCi/g above background or 6.4 pCi/g for the Split Rock site. Finally, given that a total of 103 soil samples were collected below 6" and only 9 samples deeper than 6" had Ra-226 concentrations in excess of the above value of background mean plus 3σ of 3.4, it is likely that the average Ra-226 concentration in soils in the top 6" will be well within EPA guidelines of an average of 5 pCi/g above background in the top 6" (15 cm) and 15 pCi/g above background in successive 15 centimeter increments of depth there after.

I believe that the above evaluation accurately represents the Radium-226 concentrations of soils to a depth of 6 feet in Areas 1, 5, 6, and 7. The statistical approach of including the standard deviation to a confidence level of 99% (3σ), given the large mixing which occurs during earth moving, should closely approximate the final conditions. Possible sources of the elevated Ra-226 concentrations at depth include elevated

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naturally occurring radioactive materials known to be associated with the Sweetwater area as well as windblown tailings and ore from uranium milling operations. Evidence for all three sources exists in the data to depth in Areas 5, 6, and 7 with ratios of Uranium to Radium-226 ranging from 1.2 to 0.02.

If you have any questions, please do not hesitate to call.

Sincerely

Lyda

Lyda W. Hersloff, Ph.D.

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called Wamco to check circled values.
12/21/87

[illegible]

WAMCO LAB

P. O. Box 2953 - Casper, WY 82602

ANALYSIS REPORT

COMPANY: Western Nuclear, Inc

Sample Type: Soils From Split Rock Properties

DATE Dec. 15, 1987
Date Rec'd 9/18/87
W. O. No. 7014
P. O. # D- 301689

Analysis in picoCuries per Gram except where Noted

No.	I.D.	U-Nat	Ra-226	No.	I.D.	U-Nat	Ra-226
1	1-1-1	4.2+-1.2	2.2+-0.4	37	1-5-1	2.0+-0.8	1.3+-0.3
2	6-12 1-1-2	2.5+-0.9	1.6+-0.3	38	1-5-2	1.7+-0.7	0.8+-0.2
3	12-18 1-1-3	1.7+-0.7	1.5+-0.3	39	1-5-3	2.4+-0.9	1.1+-0.3
4	18-24 1-1-4	1.1+-0.6	1.3+-0.3	40	1-5-4	4.8+-1.2	1.6+-0.3
5	1-1-5	1.7+-0.7	1.7+-0.3	41	1-5-5	8.9+-2.1	3.7+-0.5
6	1-1-6	2.8+-0.9	1.1+-0.2	42	1-5-6	10.4+-2.3	5.1+-0.6
7	1-1-7	1.1+-0.6	1.4+-0.3	43	1-5-7	5.5+-1.5	1.7+-0.3
8	1-1-8	7.4+-1.5	1.0+-0.2	44	1-5-8	1.9+-0.8	1.5+-0.3
9	1-1-9	4.0+-1.2	1.1+-0.2	45	1-5-9	1.3+-0.7	1.2+-0.3
10	1-2-1	2.0+-0.8	1.1+-0.2	46	2-1-1	0.9+-0.6	1.2+-0.3
11	1-2-2	1.1+-0.6	1.2+-0.2	47	2-1-2	0.8+-0.5	1.2+-0.3
12	1-2-3	1.7+-0.7	1.0+-0.2	48	2-1-3	1.1+-0.6	0.8+-0.2
13	1-2-4	0.8+-0.5	1.0+-0.2	49	2-1-4	~~1.0+-0.6~~	~~0.9+-0.2~~
14	1-2-5	1.7+-0.7	1.2+-0.2	50	2-1-5	1.5+-0.7	1.1+-0.3
15	1-2-6	2.2+-0.8	0.7+-0.2	51	2-1-6	0.8+-0.5	1.1+-0.3
16	1-2-7	1.1+-0.6	1.1+-0.3	52	2-1-7	1.1+-0.6	0.8+-0.2
17	1-2-8	0.6+-0.5	1.0+-0.2	53	2-1-8	4.5+-1.2	1.3+-0.3
18	1-2-9	1.1+-0.6	2.1+-0.4	54	2-1-9	1.0+-0.6	1.0+-0.3
19	1-3-1	2.2+-0.8	1.1+-0.3	55	2-2-1	1.2+-0.6	1.5+-0.3
20	1-3-2	2.2+-0.8	1.0+-0.2	56	2-2-3	1.0+-0.6	1.0+-0.2
21	1-3-3	1.7+-0.7	1.2+-0.3	57	2-2-3	1.2+-0.6	1.1+-0.3
22	1-3-4	4.5+-1.2	1.8+-0.3	58	2-2-4	0.9+-0.6	1.6+-0.3
23	1-3-5	4.7+-1.2	1.4+-0.3	59	2-2-5	0.8+-0.5	1.1+-0.3
24	1-3-6	3.9+-1.1	2.2+-0.4	60	2-2-6	0.8+-0.5	1.1+-0.3
25	1-3-7	5.7+-1.4	1.3+-0.3	61	2-2-7	0.8+-0.5	1.0+-0.3
26	1-3-8	10.0+-2.3	1.4+-0.3	62	2-2-8	2.8+-0.5	1.1+-0.3
27	1-3-9	3.0+-0.9	1.0+-0.2	63	2-2-9	0.8+-0.5	0.8+-0.2
28	1-4-1	2.2+-0.8	1.2+-0.3	64	2-3-1	1.1+-0.6	0.6+-0.2
29	1-4-2	2.3+-0.8	1.8+-0.3	65	2-3-2	0.6+-0.5	1.0+-0.2
30	1-4-3	2.7+-0.8	1.1+-0.3	66	2-3-3	1.3+-0.7	1.6+-0.3
31	1-4-4	2.5+-0.9	1.2+-0.3	67	2-3-4	0.9+-0.6	1.0+-0.3
32	1-4-5	2.8+-0.9	1.4+-0.3	68	2-3-5	0.9+-0.6	1.1+-0.3
33	1-4-6	1.1+-0.6	0.9+-0.2	69	2-3-6	1.1+-0.6	1.7+-0.3
34	1-4-7	1.4+-0.7	0.8+-0.2	70	2-3-7	0.8+-0.5	1.0+-0.3
35	1-4-8	1.3+-0.7	0.8+-0.2	71	2-3-8	1.0+-0.6	0.9+-0.2
36	1-4-9	12.5+-2.5	1.0+-0.2	72	2-3-9	0.8+-0.5	1.6+-0.3

Area 1 background x̄ 15cm [illegible] below surface
n=40
∴ [illegible] pCi/g [illegible]

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WAMCO LAB

P. O. Box 2953 - Casper, WY 82602

ANALYSIS REPORT

COMPANY: Western Nuclear, Inc

Sample Type: Soils From Split Rock Properties

DATE Dec. 15, 1987
Date Rec'd 9/18/87
W. O. No. 7014
P. O. # D- 301689

Analysis in picoCuries per Gram except where Noted

No.	I.D.	U-Nat	Ra-226	No.	I.D.	U-Nat	Ra-226
73	2-4-1	0.7+-0.5	0.9+-0.2	110	3-3-7	4.0+-1.1	1.5+-0.3
74	2-4-2	0.8+-0.5	0.9+-0.2 .05	111	3-3-8	5.2+-1.2	2.0+-0.4
75	2-4-3	1.0+-0.6	1.5+-0.3	112	3-4-1	21.0+-2.5	16.4+-1.1
76	2-4-4	3.3+-1.0	0.9+-0.2	113	3-4-2	7.8+-1.5	4.8+-0.6 .11
77	2-4-5	26.9+-4.0	1.0+-0.3 .04	114	3-4-3	20.7+-2.5	22.7+-1.3
78	2-4-6	212+-11	30.7+-1.5 .14	115	3-4-4	6.0+-1.3	6.9+-0.7 1.15
79	2-5-1	5.2+-1.2	1.3+-0.3	116	3-4-5	3.4+-1.0	5.3+-0.6 1.6
80	2-5-2	5.0+-1.2	1.0+-0.3	117	3-4-6	4.6+-1.2	1.5+-0.3 .3
81	2-5-3	1.4+-0.7	0.9+-0.2 .53 .14	118	3-4-7	8.0+-1.6	1.1+-0.3 .19
82	2-5-4	2.0+-0.8	1.5+-0.3	119	3-4-8	12.1+-1.9	1.2+-0.3 .10
83	2-5-5	1.1+-0.6	0.9+-0.2	120	3-4-9	21.0+-2.5	0.9+-0.2 .04
84	2-5-6	1.4+-0.7	0.7+-0.2	121	3-5-1	115+-5.9	33.4+-1.5
[illegible]	2-5-7	1.9+-0.7	1.0+-0.3	122	3-5-2	274+-9.1	38.5+-1.7
86	2-5-8	12.1+-1.9	9.3+-2.6	123	3-3-5	286+-9.3	3.0+-0.5
87	3-1-1	123+-6.1	1.9+-0.4	124	3-5-4	228+-8.3	1.0+-0.3
88	3-1-2	44.5+-3.7	8.9+-0.8	125	3-5-5	301+-9.5	1.3+-0.3 .03
89	3-1-3	31.6+-3.1	6.2+-0.7	126	3-5-6	416+-11	1.3+-0.3
90	3-1-4	35.9+-3.3	7.5+-0.7 .295	127	3-5-7	502+-12	0.9+-0.3
91	3-5-1	28.1+-2.9	7.8+-0.7 ±.115	128	3-5-8	139+-6.5	1.4+-0.3
92	3-1-6	21.4+-2.5	7.5+-0.7	129	3-5-9	17.4+-2.3	1.1+-0.3
93	3-1-7	102+-5.5	6.8+-0.7	130	3-6-1	63.2+-4.4	47.1+-1.8
94	3-1-8	17.8+-2.3	7.4+-0.7	131	3-6-2	34.4+-3.2	42.5+-1.7 1.2
95	3-2-1	4.6+-1.2	0.9+-0.3	132	3-6-3	51.7+-3.9	14.1+-1.0
96	3-2-2	2.9+-0.9	1.1+-0.3	133	3-6-4	54.5+-4.0	28.5+-1.4
97	3-2-3	2.3+-0.8	1.1+-0.3	134	3-6-5	87.6+-5.1	16.4+-1.1
98	3-2-4	2.3+-0.8	1.4+-0.3	135	3-6-6	89.8+-5.2	13.7+-0.9
99	3-2-5	2.2+-0.8	1.1+-0.3 .542	136	3-6-7	50.2+-3.9	15.0+-1.0
100	3-2-6	1.9+-0.7	1.1+-0.3 0.11	137	3-6-8	66.0+-4.5	11.2+-0.8
101	3-2-7	2.0+-0.8	1.2+-0.3	138	3-6-9	70.3+-4.6	14.9+-1.0
102	3-2-8	1.7+-0.7	1.2+-0.3	139	3-7-1	48.8+-3.8	28.9+-1.3 .5
103	3-2-9	2.3+-0.8	1.0+-0.3	140	3-7-2	10.9+-1.8	10.3+-0.8 .1
104	3-3-1	45.9+-3.7	18.6+-1.2	141	3-7-3	6.6+-1.4	10.0+-0.8
105	3-3-2	21.0+-2.5	4.5+-0.6	142	3-7-4	66.0+-4.5	20.7+-1.1
106	3-3-3	16.6+-2.2	1.4+-0.3	143	3-7-5	210+-7.9	29.5+-1.4
107	3-3-4	18.9+-2.4	0.3+-0.1 .775	144	3-7-6	68.9+-4.5	23.6+-1.2
108	3-3-5	14.1+-2.1	0.9+-0.3 ±.15	145	3-8-1	47.4+-3.8	23.2+-1.3
109	3-3-6	6.7+-1.4	1.5+-0.3				

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WAMCO LAB

P. O. Box 2953 - Casper, WY 82602

ANALYSIS REPORT

COMPANY: Western Nuclear, Inc

Sample Type: Soils From Split Rock Properties

DATE Dec. 15, 1987
Date Rec'd 9/18/87
W. O. No. 7014
P. O. # D- 301689

Analysis in picoCuries per Gram except where Noted

No.	I.D.	U-Nat	Ra-226
146	3-8-2	15.5+-2.2	0.8+-0.2
147	3-8-3	10.9+-1.8	1.2+-0.3
148	3-8-4	23.8+-2.7	0.9+-0.3
149	3-8-5	16.4+-2.2	0.1+-0.1
150	3-8-6	8.6+-1.6	0.8+-0.2
151	3-8-7	8.0+-1.6	0.8+-0.2
152	3-8-8	5.5+-1.3	0.8+-0.2
153	3-8-9	15.8+-2.2	1.0+-0.3
154	3-9-1	181+-7.4	142+-3.2
155	3-9-2	44.5+-3.7	154+-3.2
156	3-9-3	60.3+-4.3	7.5+-0.7
157	3-9-4	24.1+-2.7	3.5+-0.5
158	3-9-5	9.5+-1.7	2.2+-0.4
159	3-9-6	6.0+-1.3	2.0+-0.4
160	3-9-7	5.2+-1.2	1.3+-0.3
161	3-9-8	48.8+-3.8	1.8+-0.4
162	3-9-9	58.8+-4.2	1.3+-0.3
163	4-1-1	30.7+-3.0	7.3+-0.7
164	4-1-2	74.6+-4.7	2.4+-0.4
165	4-1-3	459+-11.7	1.3+-0.3
166	4-1-4	91.9+-5.3	1.0+-0.3
167	4-1-5	21.2+-2.5	1.8+-0.3
168	4-1-6	31.6+-3.1	1.0+-0.3
169	4-1-7	25.5+-2.8	1.4+-0.3
170	4-1-8	34.4+-3.2	0.7+-0.2
171	4-1-9	3.40+1.03	1.6+-0.3
172	4-2-1	3.2+-1.0	1.6+-0.3
173	4-2-2	101+-5.5	0.9+-0.3
174	4-2-3	70.3+-4.6	10.0+-0.8
175	4-2-4	5.2+-1.2	1.6+-0.3
176	4-2-5	4.6+-1.2	1.2+-0.3
177	4-2-6	3.4+-1.0	1.5+-0.3
178	4-2-7	12.1+-1.9	1.2+-0.3
179	4-2-8	15.5+-2.2	1.0+-0.2
180	4-2-9	40.2+-3.5	2.4+-0.4
181	4-3-1	2167+-26	93+-5.4
182	4-3-2	33.0+-3.1	3.3+-0.5
183	4-3-3	25.8+-2.8	1.6+-0.3
184	4-3-4	20.1+-2.5	1.5+-0.3
185	4-3-5	14.4+-2.1	2.1+-0.4
186	4-3-6	14.6+-2.1	1.8+-0.3
187	4-3-7	6.0+-1.3	0.8+-0.2
188	4-3-8	5.2+-1.2	1.2+-0.3
189	4-3-9	9.8+-1.7	20+-0.4
190	4-4-1	617+-13.6	109.2+-2.7
191	4-4-2	144+-6.6	34.9+-1.5
192	4-4-3	746+-15	45.3+-1.8
193	4-4-4	718+-15	75.2+-2.3
194	4-4-5	574+-13	5.2+-0.6
195	4-4-6	35.9+-3.3	1.2+-0.3
196	4-4-7	16.6+-2.2	3.0+-0.5
197	4-4-8	2.7+-0.9	0.9+-0.2
198	4-4-9	4.6+-1.2	0.9+-0.3
199	4-5-1	10.8+-1.8	6.9+-0.7
200	4-5-2	23.0+-2.6	19.3+-1.2
201	4-5-3	12.3+-1.9	1.9+-0.4
202	4-5-4	8.8+-1.6	3.2+-0.5
203	4-5-5	6.3+-1.4	1.3+-0.3
204	4-5-6	2.9+-0.9	1.1+-0.3
205	4-5-7	2.2+-0.8	1.3+-0.3
206	4-5-8	2.4+-0.9	2.1+-0.4
207	4-5-9	2.3+-0.8	0.8+-0.2
208	4-6-1	7.2+-1.5	2.3+-0.4
209	5-1-1	3.3+-1.0	134+-6.0
210	5-2-1	2.0+-0.8	2.4+-0.4
211	5-2-2	2.2+-0.8	1.4+-0.3
212	5-2-3	1.9+-0.7	1.4+-0.3
213	5-2-4	2.7+-0.9	1.2+-0.3
214	5-2-5	2.6+-0.9	0.9+-0.2
215	5-2-6	5.2+-1.2	1.2+-0.3
216	5-2-7	0.6+-0.4	1.3+-0.3
217	5-3-1	0.6+-0.4	3.0+-0.5
218	5-3-2	0.6+-0.4	2.3+-0.4
219	5-3-3	1.0+-0.5	8.4+-0.8

.08 .25

.16± .115

.17 .15

[illegible] 6" [illegible] .07

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WAMCO LAB

P. O. Box 2953 - Casper, WY 82602

ANALYSIS REPORT

COMPANY: Western Nuclear, Inc

Sample Type: Soils From Split Rock Properties

DATE Dec. 15, 1987
Date Rec'd 9/18/87
W. O. No. 7014
P. O. # D- 301689

Analysis in picoCuries per Gram except where Noted

No.	I.D.	U-Nat	Ra-226	No.	I.D.	U-Nat	Ra-226
220	5-3-4	1.9+-0.7	0.6+-0.2	257	6-3-5	2.3+-0.8	1.0+-0.3
221	5-3-5	1.3+-0.6	1.0+-0.3	258	6-3-6	1.7+-0.7	1.1+-0.3
222	5-3-6	1.4+-0.7	2.1+-0.4	259	6-3-7	2.3+-0.8	1.1+-0.3
223	5-3-7	2.7+-0.9	1.4+-0.3	260	6-3-8	1.7+-0.7	0.8+-0.2
224	5-3-8	1.4+-0.7	1.6+-0.3	261	6-3-9	1.1+-0.6	0.6+-0.2
225	5-3-9	1.4+-0.7	0.8+-0.2	262	6-4-1	16.4+-2.2	23.3+-1.3
226	5-4-1	488+-12	65.9+-2.1	263	6-4-2	1.4+-0.7	4.4+-0.5
227	5-4-2	9.9+-1.7	4.1+-0.5	264	6-4-3	2.0+-0.8	1.7+-0.3
228	5-4-3	4.3+-1.1	1.8+-0.3	265	6-4-4	1.9+-0.7	1.0+-0.3
229	5-4-4	5.6+-1.3	1.6+-0.3	266	6-4-5	1.7+-0.7	1.3+-0.3
230	5-4-5	3.7+-1.1	2.3+-0.4	267	6-4-6	1.9+-0.7	1.2+-0.3
231	5-4-6	3.9+-1.1	4.0+-0.5	268	6-4-7	2.6+-0.9	1.0+-0.3
232	5-4-7	3.9+-1.1	2.7+-0.4	269	6-4-8	1.7+-0.7	1.6+-0.3
233	5-4-8	2.3+-0.8	6.1+-0.6	270	6-4-9	1.4+-0.7	0.8+-0.2
234	5-4-9	6.9+-1.4	2.4+-0.4	271	7-1-1	19.5+-2.4	35.6+-1.6
235	6-1-1	38.8+-3.4	12.8+-0.9 .53	272	7-1-2	2.2+-0.8	3.0+-0.5
236	6-1-2	2.9+-0.9	1.2+-0.3	273	7-1-3	1.4+-0.7	1.5+-0.3
237	6-1-3	1.7+-0.7	44.1+-1.7 25.94	274	7-1-4	2.2+-0.8	1.3+-0.3
238	6-1-4	2.0+-0.8	1.1+-0.3	275	7-1-5	2.0+-0.8	1.1+-0.3
239	6-1-5	1.6+-0.7	1.1+-0.3 .63±	276	7-1-6	1.4+-0.7	1.0+-0.3
240	6-1-6	1.6+-0.6	3.0+-0.4 .16	277	7-1-7	1.4+-0.8	0.9+-0.2
241	6-1-7	2.4+-0.9	2.0+-0.4	278	7-1-8	1.7+-0.7	0.8+-0.2
242	6-1-8	1.9+-0.7	1.3+-0.3	279	7-1-9	1.7+-0.7	0.7+-0.2
243	6-1-9	1.1+-0.6	46.5+-1.8 47.27	280	7-2-1	13.2+-2.0	42.5+-1.7
244	6-2-1	21.0+-2.5	2.3+-0.4	281	7-2-2	2.0+-0.8	1.2+-0.3
245	6-2-2	373.2+-10.6	1.1+-0.3	282	7-2-3	1.7+-0.7	1.5+-0.3
246	6-2-3	1.9+-0.7	1.4+-0.3	283	7-2-4	3.2+-1.0	0.9+-0.3
247	6-2-4	1.7+-0.7	1.3+-0.3	284	7-2-5	2.4+-0.9	0.8+-0.2
248	6-2-5	1.4+-0.7	0.9+-0.2	285	7-2-6	1.7+-0.7	1.1+-0.3
249	6-2-6	1.9+-0.7	0.1+-0.1	286	7-2-7	1.6+-0.7	0.8+-0.2
250	6-2-7	2.2+-0.8	1.4+-0.3	287	7-2-8	1.7+-0.7	0.7+-0.2
251	6-2-8	2.2+-0.8	0.9+-0.3	288	7-2-9	1.9+-0.7	1.3+-0.3
252	6-2-9	2.0+-0.8	0.9+-0.3	289	7-3-1	7.8+-1.5	13.9+-1.0
253	6-3-1	8.8+-1.6	5.5+-0.6	290	7-3-2	3.6+-1.0	6.4+-0.7
254	6-3-2	6.6+-1.4	2.9+-0.4	291	7-3-3	1.7+-0.7	1.1+-0.3
255	6-3-3	2.2+-0.8	0.6+-0.2	292	7-3-4	1.4+-0.7	1.0+-0.3
256	6-3-4	2.3+-0.8	1.3+-0.3	293	7-3-5	1.7+-0.7	1.7+-0.4

~~I-13~~
I-13

WAMCO LAB

P. O. Box 2953 – Casper, WY 82602

ANALYSIS REPORT

COMPANY: Western Nuclear, Inc
Sample Type: Soils From Split Rock Properties

DATE Dec. 15, 1987
Date Rec'd 9/18/87
W. O. No. 7014
P. O. # D- 301689

Analysis in picoCuries per Gram except where Noted

No.	I.D.	U-Nat	Ra-226	No.	I.D.	U-Nat	Ra-226
294	7-3-6	1.9+-0.7	0.5+-0.2 .60²	331	7-7-7	1.4+-0.7	0.9+-0.3
295	7-3-7	2.3+-0.8	1.1+-0.3 .23	332	7-7-8	1.7+-0.7	1.0+-0.3
296	7-3-8	2.0+-0.8	1.1+-0.3	333	7-7-9	5.7+-1.3	3.3+-0.4
297	7-3-9	1.7+-0.7	0.9+-0.3	334	8-1-1	1.9+-0.7	0.9+-0.2
298	7-4-1	63.+-1.4	0.7+-0.2	335	8-1-2	2.7+-0.9	0.6+-0.2
299	7-4-2	2.6+-0.9	1.2+-0.3	336	8-1-3	1.6+-0.7	1.1+-0.3
300	7-4-3	2.4+-0.9	1.8+-0.3	337	8-1-4	1.6+-0.7	0.7+-0.2
301	7-4-4	1.7+-0.7	1.6+-0.3	338	8-1-5	2.3+-0.8	0.7+-0.2
302	7-4-5	2.0+-0.8	0.6+-0.2 .67³	339	8-1-6	2.0+-0.8	0.8+-0.2
303	7-4-6	1.1+-0.6	1.4+-0.3 .32	340	8-1-7	2.0+-0.8	1.0+-0.2
304	7-4-7	1.9+-0.7	1.0+-0.3	341	8-1-8	2.2+-0.8	0.7+-0.2
305	7-4-8	2.0+-0.8	0.8+-0.2	342	8-1-9	4.3+-1.1	4.2+-0.5
306	7-4-9	1.6+-0.7	1.2+-0.3	343	8-2-1	2.4+-0.9	0.8+-0.2
307	7-5-1	3.4+-1.0	12.2+-0.9	344	8-2-2	1.1+-0.6	0.6+-0.2
308	7-5-2	1.4+-0.7	1.7+-0.3	345	8-2-3	1.1+-0.6	0.6+-0.2
309	7-5-3	1.1+-0.6	1.1+-0.3	346	8-2-4	1.4+-0.7	0.9+-0.2
310	7-5-4	1.1+-0.6	1.1+-0.3	347	8-2-5	1.1+-0.6	1.0+-0.2
311	7-5-5	1.6+-0.7	0.8+-0.2 .15	248	8-2-6	0.9+-0.5	0.6+-0.2
312	7-5-6	1.4+-0.7	0.5+-0.2 + .33	349	8-2-7	1.3+-0.6	0.8+-0.2
313	7-5-7	1.7+-0.7	0.9+-0.2	350	8-2-8	1.6+-0.7	0.9+-0.2
314	7-5-8	1.7+-0.7	0.9+-0.2	351	8-2-9	1.1+-0.6	0.8+-0.2
315	7-5-9	2.6+-0.9	0.9+-0.2	352	8-3-1	1.3+-0.6	2.0+-0.3
316	7-6-1	5.7+-1.3	9.4+-0.8	353	8-3-2	1.1+-0.6	0.8+-0.2
317	7-6-2	1.7+-0.7	1.05+0.38	354	8-3-3	1.6+-0.7	0.7+-0.2
318	7-6-3	2.7+-0.9	2.2+-0.4	355	8-3-4	1.6+-0.7	1.1+-0.3
319	7-6-4	1.9+-0.76	1.0+-0.3	356	8-3-5	1.4+-0.7	0.9+-0.2
320	7-6-5	1.6+-0.7	11.1+-0.9 .75	357	8-3-6	1.9+-0.7	1.1+-0.3
321	7-6-6	0.9+-0.5	0.5+-0.2 .13	358	8-3-7	2.6+-0.9	0.7+-0.2
322	7-6-7	1.1+-0.6	0.9+-0.3	359	8-3-8	1.7+-0.7	0.8+-0.2
323	7-6-8	1.3+-0.6	1.1+-0.3	360	8-3-9	1.6+-0.7	0.5+-0.2
324	7-6-9	1.3+-0.6	1.0+-0.3	361	8-4-1	1.7+-0.7	1.1+-0.3
325	7-7-1	1.1+-0.6	1.6+-0.3	362	8-4-2	1.7+-0.7	0.9+-0.2
326	7-7-2	1.4+-0.7	1.1+-0.3	363	8-4-3	1.7+-0.7	0.6+-0.2
327	7-7-3	1.1+-0.6	0.8+-0.2	364	8-4-4	2.4+-0.9	1.4+-0.3
328	7-7-4	1.6+-0.7	1.2+-0.3	365	8-4-5	1.7+-0.7	0.9+-0.2
329	7-7-5	2.0+-0.8	1.5+-0.3	366	8-4-6	1.1+-0.6	0.8+-0.2
330	7-7-6	2.0+-0.8	0.7+-0.2	367	8-4-7	1.6+-0.7	0.8+-0.2

~~J-14~~
I-14

WAMCO LAB

P. O. Box 2953 - Casper, WY 82602

ANALYSIS REPORT

COMPANY: Western Nuclear, Inc

Sample Type: Soils From Split Rock Properties

DATE Dec. 15,1987
Date Rec'd 9/18/87
W. O. No. 7014
P. O. # D- 301689

Analysis in picoCuries per Gram except where Noted

No.	I.D.	U-Nat	Ra-226	No.	I.D.	U-Nat	Ra-226
368	8-4-0	1.1+-0.6	0.9+-0.2	405	8-8-9	0.9+-0.5	1.1+-0.2
369	8-4-9	1.6+-0.7	0.5+-0.2	406	GR-1-1	2.2+-0.8	0.7+-0.2
370	8-5-1	2.0+-0.8	1.3+-0.3				
371	8-5-2	1.7+-0.7	0.8+-0.2				
372	8-5-3	1.7+-0.7	1.0+-0.2				
373	8-5-4	0.9+-0.5	1.1+-0.3				
374	8-5-5	1.7+-0.7	0.8+-0.2				
375	8-5-6	1.4+-0.7	1.2+-0.3				
376	8-5-7	1.6+-0.7	0.7+-0.2				
377	8-5-8	1.1+-0.6	0.8+-0.2				
378	8-5-9	1.4+-0.7	1.1+-0.3				
379	8-6-1	1.4+-0.7	1.2+-0.3				
380	8-6-2	1.7+-0.7	0.6+-0.2				
381	8-6-3	0.7+-0.5	1.1+-0.3				
382	8-6-4	0.7+-0.5	0.7+-0.2				
383	8-6-5	1.1+-0.6	1.0+-0.2				
384	8-6-6	1.3+-0.6	0.7+-0.2				
385	8-6-7	1.7+-0.7	0.9+-0.2				
386	8-6-8	0.9+-0.5	1.2+-0.3				
387	8-6-9	1.1+-0.6	0.6+-0.2				
368	8-7-1	1.3+-0.6	1.4+-0.3				
389	8-7-2	0.3+-0.3	1.0+-0.2				
390	8-7-3	0.4+-0.4	0.8+-0.2				
391	8-7-4	0.6+-0.4	0.6+-0.2				
392	8-7-5	0.9+-0.5	1.4+-0.3				
393	8-7-6	0.6+-0.4	0.5+-0.2				
394	8-7-7	0.4+-0.4	0.6+-0.2				
395	8-7-8	1.6+-0.7	0.9+-0.2				
396	8-7-9	0.7+-0.5	0.6+-0.2				
397	8-8-1	2.6+-0.9	1.6+-0.3				
398	8-8-2	1.1+-0.6	1.3+-0.3				
399	8-8-3	2.2+-0.8	0.9+-0.2				
400	8-8-4	1.1+-0.6	0.9+-0.2				
401	8-8-5	1.4+-0.7	1.0+-0.2				
402	8-8-6	1.1+-0.6	0.6+-0.2				
403	8-8-7	1.3+-0.6	0.9+-0.2				
404	8-8-8	0.6+-0.4	1.1+-0.2				

APPENDIX J

NUCLEAR DENSITY AND MOISTURE CORRELATIONS

~~K-1~~ J-1

By JFL Date 10/24/91 Subject WESTERN NUCLEAR Sheet No. 1 of 12

Chkd. By [illegible] Date 1-9-92 SIMPLE LINEAR REGRESSION/CONFIDENCE Proj. No. 91 225 07

1/4" X 1/4"

PURPOSE: DERIVE RELATIONSHIP/EQUATION/CONFIDENCE FOR SAND CONE DENSITY VS. NUCLEAR DENSITY & SAND CONE MOISTURE VS. NUCLEAR MOISTURE

THE DENSITY AND MOISTURE DATA FROM INBERG-MILLER ENGINEERS IS GIVEN IN ATTACHMENT B. ALL RELATIONSHIPS ARE DERIVED FROM THIS DATA. (PAGE K-27)

DENSITY DATA

TO DERIVE THE RELATIONSHIP BETWEEN SAND CONE & NUCLEAR TEST RESULTS A SIMPLE LINEAR REGRESSION IS USED. (SEE ATTACHMENT A FOR REFERENCES, PAGE K-13)

LINEAR REGRESSION EQUATION:

(1) $$\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 (x - \bar{x})$$

$\hat{\beta}_0$ = STATISTICAL INTERCEPT = $\bar{y}$

$\hat{\beta}_1$ = STATISTICAL SLOPE = $\dfrac{S_{xy}}{S_{xx}} = \dfrac{\text{CORRECT SUM OF CROSS PRODUCTS } x * y}{\text{CORRECTED SUM OF SQUARES OF } x}$

GIVEN THE DATA IN SUMMARY TABLE B-1 (LAST TWO PAGES OF ATTACHMENT B TO THIS CALC.

\# OF POINTS = 52

ΣX (NUCLEAR) = 5366.30 $\bar{X}$ = 103.20

ΣY (SAND CONE) = 5372.40 $\bar{Y}$ = 103.32

ΣX^2 = 554707.23

ΣY^2 = 555946.32

ΣXY = 555296.27

~~K-2~~ J-2

By IFL Date 12/24/91 Subject WESTERN NUCLEAR Sheet No. 2 of 12
Chkd. By Rwm Date 1-9-92 SIMPLE LINEAR REGRESSION/CONF.INT. Proj. No. 9122507
1/4" X 1/4"

(2) $S_{xx} = \Sigma x^2 - \frac{(\Sigma x)^2}{n} = 554707.23 - \frac{(5366.30)^2}{52} = 915.39$

(3) $S'_{xy} = \Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n} = 555296.27 - \frac{5366.30 * 5372.40}{52} = 874.92$

(4) $\hat{\beta}_1 = \frac{S'_{xy}}{S_{xx}} = \frac{874.92}{915.39} = 0.96$

$\hat{\beta}_0 = 103.32 = \bar{y}$

$\therefore$

(5) $\hat{y} = 103.32 + 0.96(X - 103.20)$

$\underline{\hat{y} = 4.25 + 0.96X}$

Now 95% CONFIDENCE (BASED ON t DISTRIBUTION w/ n-2 degrees of freedom, on $\hat{\beta}_1$ (slope)

(6) $\hat{\beta}_1 - t_{\alpha/2,n-2}\sqrt{\frac{MS_E}{S_{xx}}} \le \beta_1 \le \hat{\beta}_1 + t_{\alpha/2,n-2}\sqrt{\frac{MS_E}{S_{xx}}}$

MS_E = MEAN SQUARE ERROR = $\frac{SS_E}{n-2}$
SS_E = ERROR SUM OF SQUARES = $S_{yy} - \hat{\beta}_1 S'_{xy}$

$S_{yy} = \Sigma y^2 - \frac{(\Sigma y)^2}{n} = 555946 - \frac{(5372.40)^2}{52} = 894.43$

$r^2 = \hat{\beta}_1^2 \frac{S_{xx}}{S_{yy}} = 0.94$

~~K-3~~ J-3

By JFL Date 10/24/A Subject WESTERN NUCLEAR Sheet No. 3 of 12
Chkd. By Rum Date 1-9-92 SINGLE LINEAR REGRESSION/CONFIDENCE Proj. No. 9122507
1/4" X 1/4"

$SS_E = 894.43 - (0.96)(874.92) = 54.51$

$MS_E = \frac{54.51}{(52-2)} = 1.09$

$\alpha = 1 - .95$, $n = 52$

$t_{\alpha/2, n-2} = t_{.025, 50} = 2.0105$ (t - DISTRIBUTION)

(7) $0.96 - 2.0105\sqrt{\frac{1.09}{915.39}} \le \beta_1 \le 0.96 + 2.0105\sqrt{\frac{1.09}{915.39}}$

$0.8906 \le \beta_1 \le 1.0294$

IS 95% CONFIDENT ENVELOPE ON SLOPE.

FOR INTERCEPT ($\hat{\beta}_0$):

(8) $\beta_0 = \hat{\beta}_0 \pm t_{\alpha/2, n-2}\sqrt{MSE\left[\frac{1}{n} + \frac{\bar{X}^2}{S_{xx}}\right]}$

(9) $\beta_0 = 103.32 \pm 2.0105\sqrt{1.09\left[\frac{1}{52} + \frac{(103.20)^2}{915.39}\right]}$

$96.1544 \le \beta_0 \le 110.4856$

IS 95% CONFIDENT BOUNDS ON INTERCEPT. $\hat{\beta}_0$

~~K-4~~ J-4

By JFC Date 10/24/91 Subject Western Nuclear Sheet No. 4 of 12
Chkd. By DWM Date 1-9-92 Simple Linear Regression/Conf. Proj. No. 9122507
1/4" X 1/4"

The 95% confidence interval around the data can be found by

(10) $$\hat{y}_0 \pm t_{\alpha/2, n-2}\sqrt{MSE\left[\frac{1}{n}+\frac{(x_0-\bar{x})^2}{S_{xx}}\right]}$$

or

(11) $$\hat{y}_0 \pm 2.0105\sqrt{1.09\left[\frac{1}{52}+\frac{(x_0-103.20)^2}{915.39}\right]}$$

Now construct a table. Given an $\hat{x}$ (nuclear measurement) use eqtn (5) to get $\hat{y}_0$. Then plug $\hat{x}$ into (11) and get ± 95% bound estimate.

$\hat{x}$	$\hat{y}$	$\pm\hat{y}$	$+\hat{y}$	$-\hat{y}$
90	90.65	± 0.96	91.61	89.69
94	94.49	± 0.70	95.19	93.79
98	98.33	± 0.46	98.79	97.87
102	102.17	± 0.30	102.47	101.87
106	106.01	± 0.35	106.36	105.66
110	109.85	± 0.55	110.40	109.30
114	113.69	± 0.80	114.49	112.89

~~K-5~~ J-5

By JFL Date 10/24/91 Subject VETTERn NucLER Sheet No. 5 of 12
Chkd. By sam Date 1-9-92 Single Linear Regression w/ Confide Proj. No. 9122507
1/4" X 1/4"

BUT YOU CANNOT USE THE 95% CONFIDENCE BOUNDS TO MEASURE ADEQUACY OF FUTURE POINTS BECAUSE THE 95% CONFIDENCE IS BASED ON THE PRESENT SET OF DATA AND REFLECTS THE DISTRIBUTION OF THIS SET. BUT YOU CAN USE THE FOLLOWING TO PROVIDE A 100(1-α) PERCENT PREDICTION INTERVAL.

w/ $\alpha = .05$

THIS WILL DEFINE AN INTERVAL THAT WE PREDICT THE FUTURE DATA (95% OF IT) WILL FALL.

(12) $$y_0 = \hat{y}_0 \pm t_{\alpha/2,n-2} \sqrt{MS_E \left[1 + \frac{1}{n} + \frac{(X_0 - \bar{X})^2}{S_{xx}} \right]}$$

$$\hat{y}_0 \pm 2.0105 \sqrt{1.09 \left[1 + \frac{1}{52} + \frac{(X_0 - 103.2)^2}{915.39} \right]}$$

$\hat{X}_0$	$\hat{Y}_0$	y_0
90	90.65	92.95 - 88.34
94	94.49	96.70 - 92.27
98	98.33	100.47 - 96.18
02	102.17	104.29 - 100.04
106	106.01	108.14 - 103.88
110	109.85	112.02 - 107.68
114	113.69	115.93 - 111.44

AS LONG AS THE MAJORITY OF FUTURE DATA FALLS WITHIN THIS INTERVAL WE CAN CLAIM THAT THE LINEAR REGRESSION MODEL IS CORRECT.

WESTERN NUCLEAR

J-6

9122507

√ dum 1-9-92

SAND CONE DENSITY = 4.25 + 0.96 (NUCLEAR DENSITY)

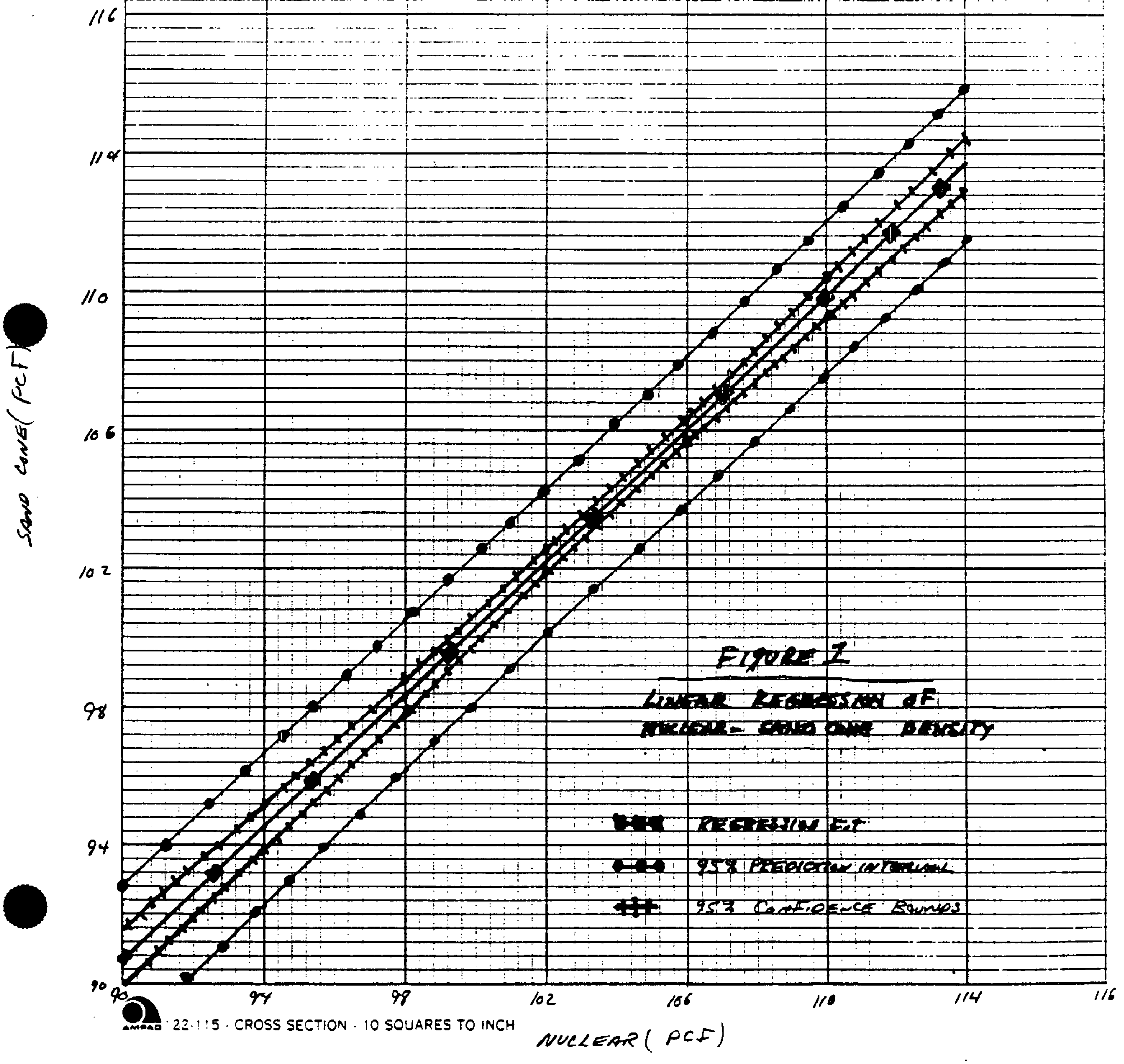

FIGURE 1

LINEAR REGRESSION OF NUCLEAR- SAND CONE DENSITY

AMPAD 22-115 · CROSS SECTION · 10 SQUARES TO INCH

~~K-7~~ J-7

CanonieEnvironmental

By JFL Date 10/24/91 Subject Western Nuclear Sheet No. 7 of 12

Chkd. By DWM Date 1-9-92 Simple Linear Regression / Confidence Proj. No. 9122507

1/4" X 1/4"

NOW MOISTURE CONTENT: (SUMMARY FROM DATA TABLES) IN ATTACHMENT B, SEE PAGE K-37)

SAND CONE	NUCLEAR
5.7	6.8
6.4	5.9
3.8	3.3
5.0	5.0
2.7	3.3
6.3	6.8
8.4	9.7
6.2	7.1
4.2	4.2
3.4	3.3
3.4	3.3
4.0	5.4
2.9	3.3
14.5	14.9
15.3	15.8
2.9	3.1
3.5	4.0
5.7	6.2
5.1	5.0
3.2	3.5
3.5	3.0
6.1	6.7
2.6	2.5
3.0	2.7
1.7	1.9
4.2	3.9
3.3	3.0
3.4	3.5
3.3	2.8
2.1	1.8
1.3	0.9
1.1	1.3

~~K-8~~ J-8

By JFL Date 10/24/91 Subject Vertex Nuclear Sheet No. 8 of 12
Chkd. By Jum Date 1-9-92 Simple Linear Regression / Correlation Proj. No. 91 225 07
1/4" X 1/4"

Moisture TABLE Cont'd

Sand Cone	NUCLEAR
1.0	1.0
1.6	1.3
1.7	1.4
2.5	2.2
2.0	1.6
1.3	1.5
2.1	1.5
2.0	1.7
1.1	1.4
1.0	1.2
1.7	1.5
2.1	1.8
1.1	1.4
1.3	1.0
2.2	1.9
1.1	13
1.5	1.9
5.0	5.4
4.7	53
5.1	45

$n = 52$

$\Sigma x = 194.7$

$\Sigma x^2 = 1209.77$

$\Sigma xy = 1156.27$

$\Sigma y = 190.30$

$\Sigma y^2 = 1114.79$

$\bar{x} = 3.744$

$\bar{y} = 3.659$

LINEAR REGRESSION: $\hat{y} = \hat{\beta}_0 + \hat{\beta}_1 (x - \bar{x})$

From (1)

CanonieEnvironmental

~~K-9~~ J-9

By JFL Date 10/24/91 Subject Western [illegible] Sheet No. 9 of 12

[illegible]d. By DWM Date 1-9-92 Simple Linear Regression/Correlation Proj. No. 9122507

1/4" X 1/4"

From (2) $S_{xx} = 1209.77 - \frac{(194.7)^2}{52} = 480.768$

From (3) $S_{xy} = 1156.27 - \frac{(194.7)(190.3)}{52} = 443.743$

From (4) $\hat{\beta}_1 = \frac{443.743}{480.768} = 0.923$

$\hat{\beta}_0 = 3.659$

From (5) , $\hat{y} = 3.659 + 0.923(\hat{x} - 3.744)$

$\underline{\hat{y} = 0.203 + 0.923\hat{x}}$

$MS_E = \frac{SS_E}{n-2}$

$SS_E = S_{yy} - \hat{\beta}_1 S_{xy}$

$S_{yy} = 1114.79 - \frac{(190.30)^2}{52} = 418.365$

$SS_E = 418.365 - 0.923(443.743) = 8.79$

$MS_E = \frac{8.79}{50} = 0.$[illegible]$58$

$t_{.025,50} = 2.0105$ (t-DISTRIBUTION)

From (6) $\beta_1 = 0.923 \pm 2.0105\sqrt{\frac{0.1758}{480.768}}$

$.8846 \leq \beta_1 \leq .9614$ 95% CONFIDENCE ON SLOPE

$r^2 = \hat{\beta}_1^2 \frac{S_{xx}}{S_{yy}} = 0.98$

By JFC Date 10/27/91 Subject [illegible] Sheet No. 10 of 12

Chkd. By [illegible] Date 1-9-92 [illegible] Proj. No. 9122507

1/4" X 1/4"

From (8)

$$\beta_0 = 3.659 \pm 2.0105 \sqrt{0.1758 \left[\frac{1}{52} + \frac{(3.744)^2}{480.768} \right]}$$

$$3.4736 \le \beta_0 \le 3.8444$$ 95% Confidence on intercept.

∴ 95% Confidence About the data is:

From (10)

$$\hat{y}_0 \pm 2.0105 \sqrt{0.1758 \left[\frac{1}{52} + \frac{(x_0 - 3.744)^2}{480.768} \right]}$$

$\hat{x}$	$\hat{y}$	$\pm\hat{y}$	$+\hat{y}$	$-\hat{y}$
1	1.126	.1575	1.283	0.968
2	2.049	.1348	2.184	1.914
4	3.895	.1173	4.012	3.778
6	5.741	.1456	5.887	5.595
8	7.587	.2011	7.788	7.386
10	9.433	.2674	9.700	9.166
12	11.279	.3382	11.617	10.941
14	13.125	.4113	13.536	12.714
16	14.971	.4855	15.457	14.486

CanonieEnvironmental ~~K-11~~ J-11

By JEL Date 6/24/91 Subject Western McLean Sheet No. 11 of 12

Chkd. By DWM Date 1-9-92 Simple Linear Regression/Confidence Proj. No. 9122507

1/4" X 1/4"

NEW 95% PREDICTED INTERVAL

From (12)

$$Y_0 = \hat{Y}_0 \pm 2.0105 \sqrt{0.1758 \left[1 + \frac{1}{52} + \frac{(X_0 - 3.744)^2}{480.768}\right]}$$

$\hat{X}_0$	$\hat{Y}_0$	Y_0
1	1.126	1.984 — .268
2	2.049	2.903 — 1.195
4	3.895	4.746 — 3.044
6	5.741	6.596 — 4.886
8	7.587	8.454 — 6.720
10	9.433	10.317 — 8.549
12	11.279	12.187 — 10.371
14	13.125	14.063 — 12.187
16	14.971	15.944 — 13.998

DATA IS plotted in Figure 2. IF NEW DATA FALLS within 95% PREDICTION INTERVAL, THEN REGRESSION Equation IS good.

Figure 2
MOISTURE CONTENT

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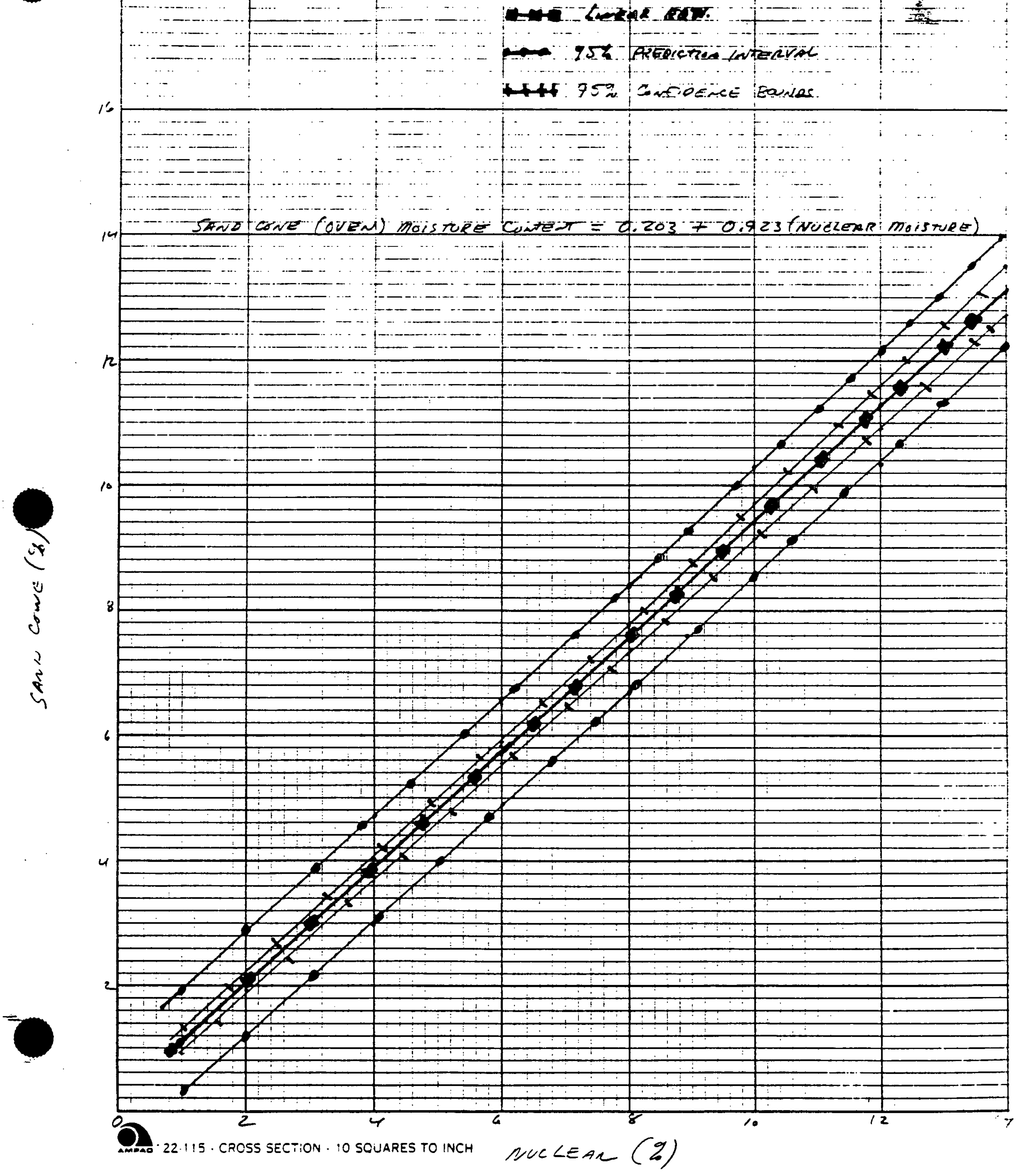

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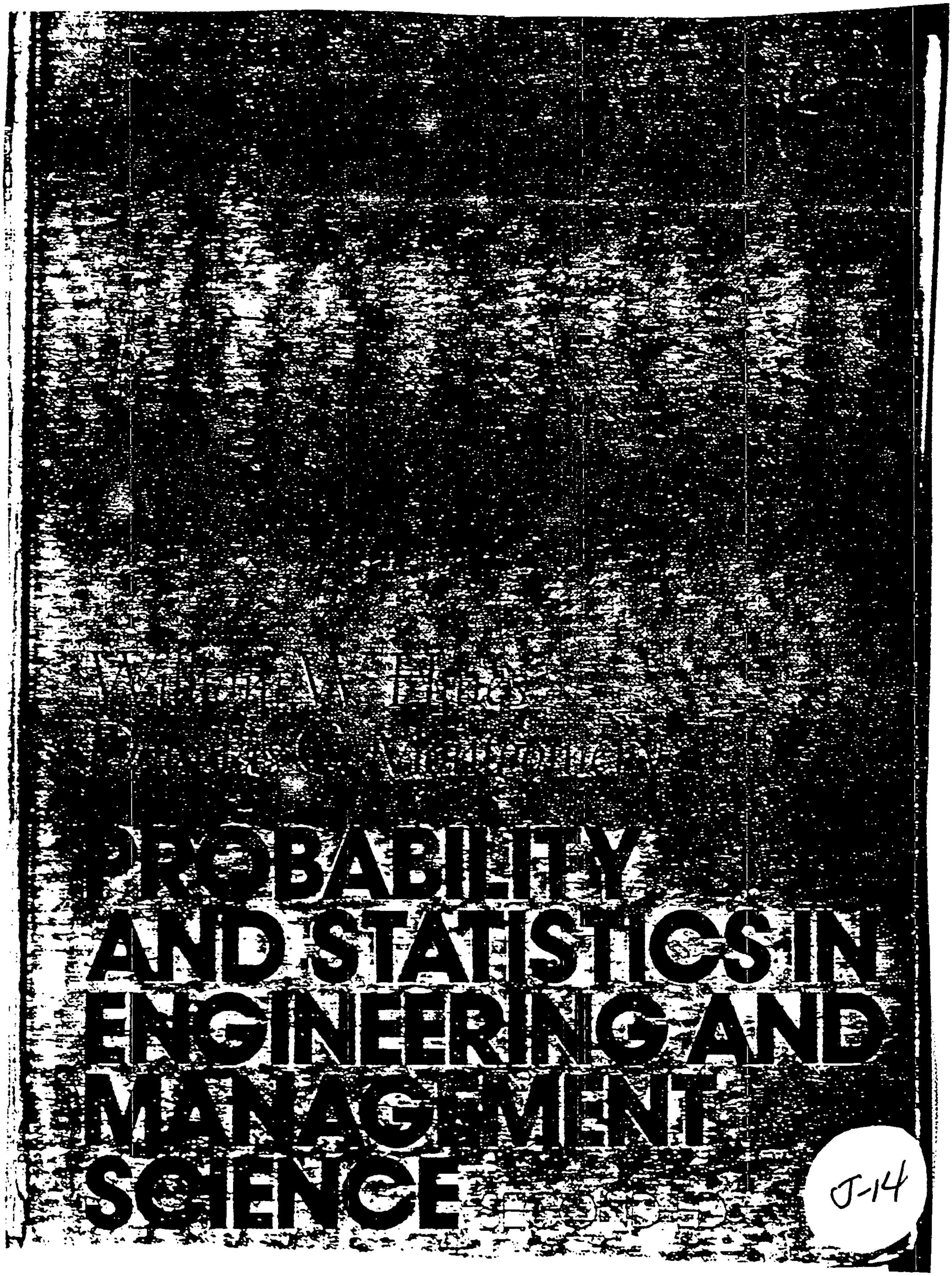
ATTACHMENT A

REFERENCES



William W. Hines
Douglas C. Montgomery

PROBABILITY AND STATISTICS IN ENGINEERING AND MANAGEMENT SCIENCE

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12-1 Simple Linear Regression

We wish to determine the relationship between a single independent variable x and a dependent variable y. The independent variable x is assumed to be a continuous mathematical variable, controllable by the experimenter. Suppose that the true relationship between y and x is a straight line, and that the observation y at each level of x is a random variable. Now, the expected value of y for each value of x is

$$E(y|x) = \beta_0 + \beta_1 x \tag{12-1}$$

where the intercept β_0 and the slope β_1 are unknown constants. We assume that each observation, y, can be described by the model

$$y = \beta_0 + \beta_1 x + \epsilon \tag{12-2}$$

where ϵ is a random error with mean zero and variance σ^2. The $\{\epsilon\}$ are also assumed to be uncorrelated random variables. The regression model of Equation (12-2) involving only a single independent variable x is often called the *simple* linear regression model.

Suppose that we have n pairs of observations, say (y_1, x_1), (y_2, x_2), ..., (y_n, x_n). These data may be used to estimate the unknown parameters β_0 and β_1 in Equation (12-2). Our estimation procedure will be the method of least squares. That is, we will estimate β_0 and β_1 so that the sum of squares of the deviations between the observations and the regression line is a minimum. Now using Equation (12-2), we may write

$$y_i = \beta_0 + \beta_1 x_i + \epsilon_i, \qquad i = 1, 2, \ldots, n$$

and the sum of squares of the deviations of the observations from the true regression line is

$$L = \sum_{i=1}^{n} \epsilon_i^2 = \sum_{i=1}^{n} (y_i - \beta_0 - \beta_1 x_i)^2 \tag{12-3}$$

Minimizing the least squares function L is simplified if we rewrite the model, Equation (12-2), as

$$y = \beta_0' + \beta_1(x - \bar{x}) + \epsilon \tag{12-4}$$

where $\bar{x} = (1/n)\sum_{i=1}^{n} x_i$ and $\beta_0' = \beta_0 + \beta_1 \bar{x}$. In Equation (12-4) we have corrected the independent variable for its mean, resulting in a transformation on the intercept. Equation (12-4) is frequently called the transformed simple linear regression model.

Employing the transformed model, the least squares function is

$$L = \sum_{i=1}^{n} [y_i - \beta_0' - \beta_1(x_i - \bar{x})]^2 \tag{12-5}$$

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T least squares estimators of β_0 and β_1, say $\hat\beta_0$ and $\hat\beta_1$, must satisfy

$$\frac{\partial L}{\partial \beta_0'}\bigg|_{\hat\beta_0, \hat\beta_1} = -2\sum_{i=1}^{n}[y_i - \hat\beta_0' - \hat\beta_1(x_i - \bar{x})] = 0$$

$$\frac{\partial L}{\partial \beta_1}\bigg|_{\hat\beta_0, \hat\beta_1} = -2\sum_{i=1}^{n}[y_i - \hat\beta_0' - \hat\beta_1(x_i - \bar{x})](x_i - \bar{x}) = 0$$

Simplifying these two equations yields

$$n\hat\beta_0' = \sum_{i=1}^{n} y_i$$

$$\hat\beta_1 \sum_{i=1}^{n}(x_i - \bar{x})^2 = \sum_{i=1}^{n} y_i(x_i - \bar{x}) \qquad (12\text{-}6)$$

Equations (12-6) are called the *least squares normal equations*. The solution to the normal equations is

$$\hat\beta_0' = \frac{1}{n}\sum_{i=1}^{n} y_i = \bar{y} \qquad (12\text{-}7)$$

$$\hat\beta_1 = \frac{\sum_{i=1}^{n} y_i(x_i - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad (12\text{-}8)$$

Therefore, $\hat\beta_0'$ and $\hat\beta_1$ are the least squares estimators of the transformed intercept and slope, respectively. The estimated simple linear regression model is then

$$\hat{y} = \hat\beta_0' + \hat\beta_1(x - \bar{x}) \qquad (12\text{-}9)$$

To present the results in terms of the original intercept β_0, note that

$$\hat\beta_0 = \hat\beta_0' - \hat\beta_1\bar{x}$$

and the corresponding estimated simple linear regression model is

$$\hat{y} = \hat\beta_0 + \hat\beta_1 x \qquad (12\text{-}10)$$

Equations (12-9) and (12-10) are equivalent; that is, they both produce the same value of $\hat{y}$ for a given value of x.

Notationally, it is convenient to give special symbols to the numerator and denominator of Equation (12-8). That is, let

$$S_{xx} = \sum_{i=1}^{n}(x_i - \bar{x})^2 = \sum_{i=1}^{n} x_i^2 - \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n} \qquad (12\text{-}11)$$

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$$S_{xy} = \sum_{i=1}^{n} y_i(x_i - \bar{x}) = \sum_{i=1}^{n} x_i y_i - \frac{\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n} \tag{12-12}$$

We call S_{xx} the corrected sum of squares of x and S_{xy} the corrected sum of cross products of x and y. The extreme right-hand sides of Equations (12-11) and (12-12) are the usual computational formulas. Using this new notation, the least squares estimator of the slope is

$$\hat{\beta}_1 = \frac{S_{xy}}{S_{xx}} \tag{12-13}$$

- **Example 12-1.** A chemical engineer is investigating the effect of process operating temperature on product yield. The study results in the following data:

Temperature, °C (x)	100	110	120	130	140	150	160	170	180	190
Yield, % (y)	45	51	54	61	66	70	74	78	85	89

These pairs of points are plotted in Fig. 12-1. Such a display is called a *scatter*

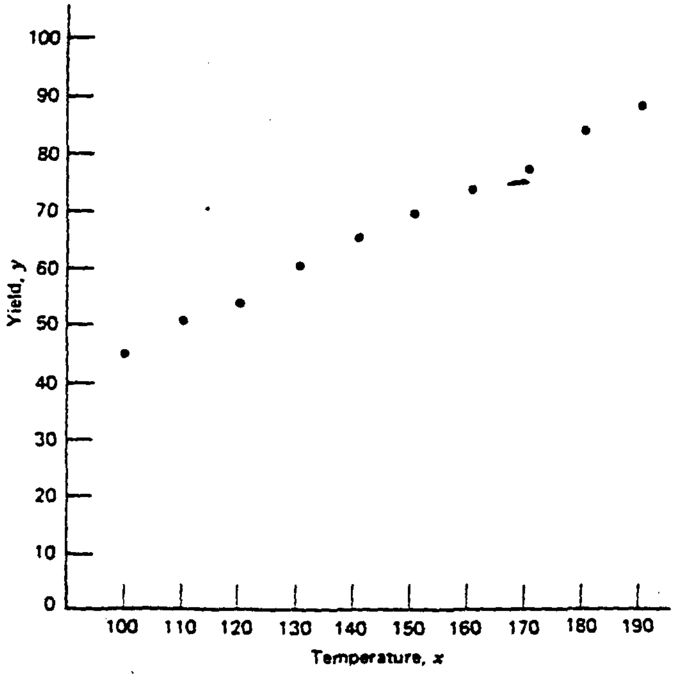

Fig. 12-1. Scatter diagram of yield versus temperature.

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diagram. Examination of this scatter diagram indicates that there is a strong relationship between yield and temperature, and the tentative assumption of the straight-line model $y = \beta_0 + \beta_1 x + \epsilon$ appears to be reasonable. The following quantities may be computed:

$$n = 10 \qquad \sum_{i=1}^{10} x_i = 1450 \qquad \sum_{i=1}^{10} y_i = 673 \qquad \bar{x} = 145 \qquad \bar{y} = 67.3$$

$$\sum_{i=1}^{10} x_i^2 = 218{,}500 \qquad \sum_{i=1}^{10} y_i^2 = 47{,}225 \qquad \sum_{i=1}^{10} x_i y_i = 101{,}570$$

From Equations (12-11) and (12-12), we find

$$S_{xx} = \sum_{i=1}^{10} x_i^2 - \frac{\left(\sum_{i=1}^{10} x_i\right)^2}{10} = 218{,}500 - \frac{(1450)^2}{10} = 8250$$

and

$$S_{xy} = \sum_{i=1}^{10} x_i y_i - \frac{\left(\sum_{i=1}^{10} x_i\right)\left(\sum_{i=1}^{10} y_i\right)}{10} = 101{,}570 - \frac{(1450)(673)}{10} = 3985$$

Therefore, the least squares estimates of the slope and intercept are

$$\hat{\beta}_1 = \frac{S_{xy}}{S_{xx}} = \frac{3985}{8250} = .48303$$

and

$$\hat{\beta}_0' = \bar{y} = 67.3$$

$\hat{y} = \bar{y} + \hat{\beta}(x - \bar{x})$

$\hat{y} = \bar{y} + \hat{\beta}x - \hat{\beta}\bar{x}$

$\hat{y} = (\bar{y} - \hat{\beta}\bar{x}) + \hat{\beta}x$

$= 67.3 + .48303x -$ [illegible]

The estimated simple linear regression model is

$$\hat{y} = \hat{\beta}_0' + \hat{\beta}_1(x - \bar{x})$$

or

$$\hat{y} = 67.3 + .48303(x - 145)$$

To express the model in terms of the original intercept, note that

$$\begin{aligned} \hat{\beta}_0 &= \hat{\beta}_0' - \hat{\beta}_1\bar{x} \\ &= 67.3 - .48303(145) = -2.73939 \end{aligned}$$

and, consequently, we have

$$\hat{y} = -2.73939 + .48303x$$

Since we have only tentatively assumed the straight-line model to be appropriate, we will want to investigate the adequacy of the model. The statistical properties of the least squares estimators $\hat{\beta}_0$ (or $\hat{\beta}_0'$) and $\hat{\beta}_1$ are

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useful in assessing model adequacy. The estimators $\hat{\beta}_0$ (or $\hat{\beta}_0'$) and $\hat{\beta}_1$ are random variables, since they are just linear combinations of the y_i, and the y_i are random variables. We will investigate the bias and variance properties of these estimators. Consider first $\hat{\beta}_1$. The expected value of $\hat{\beta}_1$ is

$$\begin{aligned}
E(\hat{\beta}_1) &= E\left(\frac{S_{xy}}{S_{xx}}\right) \\
&= \frac{1}{S_{xx}} E\left[\sum_{i=1}^{n} y_i(x_i - \bar{x})\right] \\
&= \frac{1}{S_{xx}} E\left[\sum_{i=1}^{n} (\beta_0' + \beta_1(x_i - \bar{x}) + \epsilon_i)(x_i - \bar{x})\right] \\
&= \frac{1}{S_{xx}} \left\{ E\left[\beta_0' \sum_{i=1}^{n}(x_i - \bar{x})\right] + E\left[\beta_1 \sum_{i=1}^{n}(x_i - \bar{x})^2\right] + E\left[\sum_{i=1}^{n} \epsilon_i (x_i - \bar{x})\right]\right\} \\
&= \frac{1}{S_{xx}} \beta_1 S_{xx} \\
&= \beta_1
\end{aligned}$$

since $\sum_{i=1}^{n} (x_i - \bar{x}) = 0$, and by assumption $E(\epsilon_i) = 0$. Thus, $\hat{\beta}_1$ is an *unbiased* estimator of the true slope β_1. Now consider the variance of $\hat{\beta}_1$. Since we have assumed that $V(\epsilon_i) = \sigma^2$, it follows that $V(y_i) = \sigma^2$, and

$$\begin{aligned}
V(\hat{\beta}_1) &= V\left(\frac{S_{xy}}{S_{xx}}\right) \\
&= \frac{1}{S_{xx}^2} V\left[\sum_{i=1}^{n} y_i(x_i - \bar{x})\right] \qquad (12\text{-}14)
\end{aligned}$$

The random variables $\{y_i\}$ are uncorrelated because the $\{\epsilon_i\}$ are uncorrelated. Therefore, the variance of the sum in Equation (12-14) is just the sum of the variances, and the variance of each term in the sum, say $V[y_i(x_i - \bar{x})]$, is $\sigma^2(x_i - \bar{x})^2$. Thus,

$$\begin{aligned}
V(\hat{\beta}_1) &= \frac{1}{S_{xx}^2} \sigma^2 \sum_{i=1}^{n} (x_i - \bar{x})^2 \\
&= \frac{\sigma^2}{S_{xx}} \qquad (12\text{-}15)
\end{aligned}$$

By using a similar approach, we can show that

$$E(\hat{\beta}_0') = \beta_0' \qquad V(\hat{\beta}_0') = \frac{\sigma^2}{n} \qquad (12\text{-}16)$$

and

$$E(\beta_0) = \beta_0 \qquad V(\hat{\beta}_0) = \sigma^2\left[\frac{1}{n} + \frac{\bar{x}^2}{S_{xx}}\right] \qquad (12\text{-}17)$$

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To find $V(\hat{\beta}_0')$, we must make use of the result $\text{Cov}(\hat{\beta}_0', \hat{\beta}_1) = 0$. However, the covariance of $\hat{\beta}_0$ and $\hat{\beta}_1$ is not zero; in fact, $\text{Cov}(\hat{\beta}_0, \hat{\beta}_1) = -\sigma^2\bar{x}/S_{xx}$. (Refer to Exercises 12-14 and 12-15.) Note that $\hat{\beta}_0'$ and $\hat{\beta}_0$ are unbiased estimators of β_0' and β_0, respectively.

It is usually necessary to obtain an estimate of σ^2. The difference between the observation y_i and the corresponding predicted value $\hat{y}_i$, say $e_i = y_i - \hat{y}_i$, is called a *residual*. The sum of the squares of the residuals, or the error sum of squares, would be

$$SS_E = \sum_{i=1}^{n} e_i^2$$

$$= \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \qquad (12\text{-}18)$$

A more convenient computing formula for SS_E may be found by substituting the estimated model $\hat{y}_i = \bar{y} + \hat{\beta}_1(x_i - \bar{x})$ into Equation (12-18) and simplifying as follows:

$$SS_E = \sum_{i=1}^{n} [y_i - \bar{y} - \hat{\beta}_1(x_i - \bar{x})]^2$$

$$= \sum_{i=1}^{n} [y_i^2 + \bar{y}^2 + \hat{\beta}_1^2(x_i - \bar{x})^2 - 2\bar{y}y_i - 2\hat{\beta}_1 y_i(x_i - \bar{x}) - 2\hat{\beta}_1\bar{y}(x_i - \bar{x})]$$

$$= \sum_{i=1}^{n} y_i^2 + n\bar{y}^2 + \hat{\beta}_1^2 S_{xx} - 2\bar{y}\sum_{i=1}^{n} y_i - 2\hat{\beta}_1 S_{xy} - 2\hat{\beta}_1\bar{y}\sum_{i=1}^{n}(x_i - \bar{x}) \qquad (12\text{-}19)$$

The last term in Equation (12-19) is zero, $2\bar{y}\sum_{i=1}^{n} y_i = 2n\bar{y}^2$, and $\hat{\beta}_1^2 S_{xx} = \hat{\beta}_1(S_{xy}/S_{xx})S_{xx} = \hat{\beta}_1 S_{xy}$. Therefore, Equation (12-19) becomes

$$SS_E = \sum_{i=1}^{n} y_i^2 - n\bar{y}^2 - \hat{\beta}_1 S_{xy}$$

But $\sum_{i=1}^{n} y_i^2 - n\bar{y}^2 = \sum_{i=1}^{n} (y_i - \bar{y})^2 \equiv S_{yy}$, say, so we may write SS_E as

$$SS_E = S_{yy} - \hat{\beta}_1 S_{xy} \qquad (12\text{-}20)$$

The expected value of SS_E is $E(SS_E) = (n-2)\sigma^2$. Therefore,

$$\hat{\sigma}^2 = \frac{SS_E}{n-2} \equiv MS_E \qquad (12\text{-}21)$$

is an unbiased estimator of σ^2.

Regression analysis is widely used, and frequently *misused*. There are several common abuses of regression that should be briefly mentioned. Care should be taken in selecting variables with which to construct regression models and in determining the form of the approximating function. It is quite possible to develop statistical relationships among variables that are com-

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TABLE 12-2 **Testing for Significance of Regression, Example 12-2**

Source of Variation	Sum of Squares	Degree of Freedom	Mean Square	F_0
Regression	1924.87	1	1924.87	2138.74
Error	7.23	8	.90	
Total	1932.10	9		

The regression sum of squares is

$$SS_R = \hat{\beta}_1 S_{xy} = (.48303)(3985) = 1924.87$$

and the error sum of squares is

$$\begin{aligned} SS_E &= S_{yy} - SS_R \\ &= 1932.10 - 1924.87 \\ &= 7.23 \end{aligned}$$

The analysis of variance for testing $H_0: \beta_1 = 0$ is summarized in Table 12-2. Noting that $F_0 = 2138.74 > F_{.01,1,8} = 11.26$, we reject H_0 and conclude that $\beta_1 \neq 0$.

12-3 Interval Estimation in Simple Linear Regression

In addition to point estimates of the slope and intercept, it is possible to obtain confidence interval estimates of these parameters. The width of these confidence intervals is a measure of the overall quality of the regression line. If the ϵ_i are normally and independently distributed, then

$$(\hat{\beta}_1 - \beta_1)/\sqrt{MS_E/S_{xx}} \quad \text{and} \quad (\hat{\beta}_0 - \beta_0)\Big/\sqrt{MS_E\left[\frac{1}{n} + \frac{\bar{x}^2}{S_{xx}}\right]}$$

are both distributed as t with $n-2$ degrees of freedom. Therefore, a $100(1-\alpha)$ percent confidence interval on the slope β_1 is given by

$$\hat{\beta}_1 - t_{\alpha/2,n-2}\sqrt{\frac{MS_E}{S_{xx}}} \leq \beta_1 \leq \hat{\beta}_1 + t_{\alpha/2,n-2}\sqrt{\frac{MS_E}{S_{xx}}} \tag{12-34}$$

Similarly, a $100(1-\alpha)$ percent confidence interval on the intercept β_0 is

$$\hat{\beta}_0 - t_{\alpha/2,n-2}\sqrt{MS_E\left[\frac{1}{n} + \frac{\bar{x}^2}{S_{xx}}\right]} \leq \beta_0 \leq \hat{\beta}_0 + t_{\alpha/2,n-2}\sqrt{MS_E\left[\frac{1}{n} + \frac{\bar{x}^2}{S_{xx}}\right]} \tag{12-35}$$

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Example 12-3. We will find a 95 percent confidence interval on the slope of the regression line using the data in Example 12-1. Recall that $\hat{\beta}_1 = .48303$, $S_{xx} = 8250$, and $MS_E = .90$ (see Table 12-2). Then, from Equation (12-34) we find

$$\hat{\beta}_1 - t_{.025,8}\sqrt{\frac{MS_E}{S_{xx}}} \le \beta_1 \le \hat{\beta}_1 + t_{.025,8}\sqrt{\frac{MS_E}{S_{xx}}}$$

or

$$.48303 - 2.306\sqrt{\frac{.90}{8250}} \le \beta_1 \le .48303 + 2.306\sqrt{\frac{.90}{8250}}$$

This simplifies to

$$.45894 \le \beta_1 \le .50712$$

A confidence interval may be constructed for the mean response at a specified x, say x_0. This is a confidence interval about $E(y|x_0)$ and is often called a confidence interval about the regression line. Since $E(y|x_0) = \beta_0' + \beta_1(x_0 - \bar{x})$, we may obtain a point estimate of $E(y|x_0)$ from the estimated model as

$$\widehat{E(y|x_0)} \equiv \hat{y}_0 = \hat{\beta}_0' + \hat{\beta}_1(x_0 - \bar{x})$$

Now $\hat{y}_0$ is an unbiased point estimator of $E(y|x_0)$. That is, $E(\hat{y}_0) = \beta_0' + \beta_1(x_0 - \bar{x})$, since $\hat{\beta}_0'$ and $\hat{\beta}_1$ are unbiased estimators of β_0' and β_1. The variance of $\hat{y}_0$ is

$$V(\hat{y}_0) = \sigma^2\left[\frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}\right]$$

since $\mathrm{Cov}(\hat{\beta}_0'\hat{\beta}_1) = 0$. Also, $\hat{y}_0$ is normally distributed, as $\hat{\beta}_0'$ and $\hat{\beta}_1$ are normally distributed. Therefore, a $100(1-\alpha)$ percent confidence interval about the true regression line at $x = x_0$ may be computed from

$$\hat{y}_0 - t_{\alpha/2,n-2}\sqrt{MS_E\left(\frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}\right)} \le E(y|x_0)$$
$$\le \hat{y}_0 + t_{\alpha/2,n-2}\sqrt{MS_E\left(\frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}\right)} \quad (12\text{-}36)$$

The width of the confidence interval for $E(y|x_0)$ is a function of x_0. The interval width is a minimum for $x_0 = \bar{x}$ and widens as $|x_0 - \bar{x}|$ increases.

Example 12-4. We will construct a 95 percent confidence interval about the regression line for the data in Example 12-1. The estimated model is $\hat{y}_0 = -2.73939 + .48303x_0$, and the 95 percent confidence interval on $E(y|x_0)$ is

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TABLE 12-3 **Confidence Interval about the Regression Line, Example 12-4**

x_0	100	110	120	130	140	150	160	170	180	190
$\hat{y}_0$	45.56	50.39	55.22	60.05	64.88	69.72	74.55	79.38	84.21	89.04
95% confidence limits	±1.30	±1.10	±.93	±.79	±.71	±.71	±.79	±.93	±1.10	±1.30

found from Equation (12-36) as

$$\left[\hat{y}_0 \pm 2.306\sqrt{.90\left(\frac{1}{10}+\frac{(x_0-145)^2}{8250}\right)}\right]$$

The fitted values $\hat{y}_0$ and the corresponding 95 percent confidence limits for the points $x_0 = x_i$, $i = 1, 2, \ldots, 10$, are displayed in Table 12-3. To illustrate the use of this table, we may find the 95 percent confidence interval on the true mean process yield at $x_0 = 140$°C (say) as

$$64.88 - .71 \leq E(y|x_0 = 140) \leq 64.88 + .71$$

or

$$64.17 \leq E(y|x_0 = 140) \leq 65.49$$

The estimated model and the 95 percent confidence interval about the regression line are shown in Fig. 12-4.

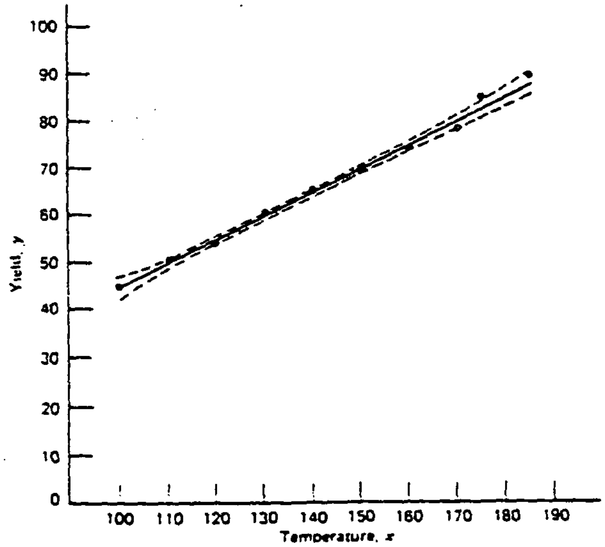

Fig. 12-4. A 95 percent confidence interval about the regression line for Example 12-4.

Example 12-4

70	180	190
38	84.21	89.04
3	±1.10	±1.30

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12-4 Prediction of New Observations

An important application of the regression model is the prediction of new or future observations y corresponding to a specified level of the independent variable x. If x_0 is the value of the independent variable of interest, then

$$\hat{y}_0 = \hat{\beta}_0 + \hat{\beta}_1 x_0 \tag{12-37}$$

is the point estimate of the new or future value of the response y_0.

Now consider obtaining an interval estimate of this future observation y_0. This new observation is independent of the observations used to develop the regression model. Therefore, the confidence interval about the regression line, Equation (12-36), is inappropriate, since it is based only on the data used to fit the regression model. The confidence interval about the regression line refers to the true mean response at $x = x_0$ (that is, a *population parameter*), not to *future* observations.

Let y_0 be the future observations at $x = x_0$, and let $\hat{y}_0$ given by Equation (12-37) be the estimator of y_0. Note that the random variable

$$\psi = y_0 - \hat{y}_0$$

is normally distributed with mean zero and variance

$$\begin{aligned} V(\psi) &= V(y_0 - \hat{y}_0) \\ &= \sigma^2\left[1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}\right] \end{aligned}$$

because y_0 is independent of $\hat{y}_0$. Thus, the $100(1-\alpha)$ percent prediction interval on a future observations at x_0 is

$$\begin{aligned} \hat{y}_0 - t_{\alpha/2,n-2}\sqrt{MS_E\left[1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}\right]} &\le y_0 \\ \le \hat{y}_0 + t_{\alpha/2,n-2}\sqrt{MS_E\left[1 + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}\right]} & \end{aligned} \tag{12-38}$$

Notice that the prediction interval is of minimum width at $x_0 = \bar{x}$ and widens as $|x_0 - \bar{x}|$ increases. By comparing Equation (12-38) with Equation (12-36), we observe that the prediction interval at x_0 is always wider than the confidence interval at x_0. This results because the prediction interval depends on both the error from the estimated model and the error associated with future observations.

We may also find a $100(1-\alpha)$ percent prediction interval on the *mean* of k future observations on the response at $x = x_0$. Let $\bar{y}_0$ be the mean of k future observations at $x = x_0$. The $100(1-\alpha)$ percent prediction interval on $\bar{y}_0$ is

$$\begin{aligned} \hat{y}_0 - t_{\alpha/2,n-2}\sqrt{MS_E\left[\frac{1}{k} + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}\right]} &\le \bar{y}_0 \\ \le \hat{y}_0 + t_{\alpha/2,n-2}\sqrt{MS_E\left[\frac{1}{k} + \frac{1}{n} + \frac{(x_0 - \bar{x})^2}{S_{xx}}\right]} & \end{aligned} \tag{12-39}$$

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To illustrate the construction of a prediction interval, suppose we use the data in Example 12-1 and find a 95 percent prediction interval on the next observation on the process yield at $x_0 = 160°\text{C}$. Using Equation (12-38), we find that the prediction interval is

$$74.55 - 2.306\sqrt{.90\left[1 + \frac{1}{10} + \frac{(160-145)^2}{8250}\right]} \le y_0$$
$$\le 74.55 + 2.306\sqrt{.90\left[1 + \frac{1}{10} + \frac{(160-145)^2}{8250}\right]}$$

which simplifies to

$$72.21 \le y_0 \le 76.89$$

12-5 Measuring the Adequacy of the Regression Model

Fitting a regression model requires several assumptions. Estimation of the model parameters requires the assumption that the errors are uncorrelated random variables with mean zero and constant variance. Tests of hypotheses and interval estimation require that the errors are normally distributed. In addition, we assume that the order of the model is correct; that is, if we fit a first-order polynomial, then we are assuming that the phenomena actually behaves in a first-order manner.

The analyst should always consider the validity of these assumptions to be doubtful and conduct analyses to examine the adequacy of the model that has been tentatively entertained. In this section we discuss methods useful in this respect.

12-5.1 Residual Analysis

We define the residuals as $e_i = y_i - \hat{y}_i$, $i = 1, 2, \ldots, n$, where y_i is an observation and $\hat{y}_i$ is the corresponding estimated value from the regression model. Analysis of the residuals is frequently helpful in checking the assumption that the errors are $\text{NID}(0, \sigma^2)$ and in determining if additional terms in the model would be useful.

As an approximate check of normality, the experimenter can construct a frequency histogram of the residuals or plot them on normal probability paper. It requires judgment to assess the abnormality of such plots. One may also standardize the residuals by computing $d_i = e_i/\sqrt{MS_E}$, $i = 1, 2, \ldots, n$. If the errors are $\text{NID}(0, \sigma^2)$, then approximately 95 percent of the standardized residuals should fall in the interval $(-2, +2)$. Residuals far outside this interval may indicate the presence of an *outlier*; that is, an observation that is not typical of the rest of the data. Various rules have been proposed for discarding outliers. However, sometimes outliers provide important information about unusual circumstances of interest to the experimenter and

J-25
~~K-25~~

√ sum
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TABLE IV **Percentage Points of the *t* Distribution**

= k =

degrees freedom

ν \ α	40	25	.10	05	.025	.01	.005	.0025	001	.0005
1	325	1.000	3.078	6.314	12.706	31.821	63.657	127.32	318.31	636.62
2	289	816	1.886	2.920	4.303	6.965	9.925	14.089	23.326	31.598
3	277	765	1.638	2.353	3.182	4.541	5.841	7.453	10.213	12.924
4	271	741	1.533	2.132	2.776	3.747	4.604	5.598	7.173	8.610
5	267	727	1.476	2.015	2.571	3.365	4.032	4.773	5.893	6.869
6	.265	718	1.440	1.943	2.447	3.143	3.707	4.317	5.208	5.959
7	.263	.711	1.415	1.895	2.365	2.998	3.499	4.029	4.785	5.408
8	.262	706	1.397	1.860	2.306	2.896	3.355	3.833	4.501	5.041
9	.261	703	1.383	1.833	2.262	2.821	3.250	3.690	4.297	4.781
10	.260	700	1.372	1.812	2.228	2.764	3.169	3.581	4.144	4.587
11	.260	.697	1.363	1.796	2.201	2.718	3.106	3.497	4.025	4.437
12	.259	.695	1.356	1.782	2.179	2.681	3.055	3.428	3.930	4.318
13	.259	.694	1.350	1.771	2.160	2.650	3.012	3.372	3.852	4.221
14	.258	.692	1.345	1.761	2.145	2.624	2.977	3.326	3.787	4.140
15	.258	691	1.341	1.753	2.131	2.602	2.947	3.286	3.733	4.073
16	.258	.690	1.337	1.746	2.120	2.583	2.921	3.252	3.686	4.015
17	.257	.689	1.333	1.740	2.110	2.567	2.898	3.222	3.646	3.965
18	.257	.688	1.330	1.734	2.101	2.552	2.878	3.197	3.610	3.922
19	.257	.688	1.328	1.729	2.093	2.539	2.861	3.174	3.579	3.883
20	.257	.687	1.325	1.725	2.086	2.528	2.845	3.153	3.552	3.850
21	257	.686	1.323	1.721	2.080	2.518	2.831	3.135	3.527	3.819
22	.256	686	1.321	1.717	2.074	2.508	2.819	3.119	3.505	3.792
23	.256	685	1.319	1.714	2.069	2.500	2.807	3.104	3.485	3.767
24	.256	685	1.318	1.711	2.064	2.492	2.797	3.091	3.467	3.745
25	.256	.684	1.316	1.708	2.060	2.485	2.787	3.078	3.450	3.725
26	.256	.684	1.315	1.706	2.056	2.479	2.779	3.067	3.435	3.707
27	.256	.684	1.314	1.703	2.052	2.473	2.771	3.057	3.421	3.690
28	.256	.683	1.313	1.701	2.048	2.467	2.763	3.047	3.408	3.674
29	.256	683	1.311	1.699	2.045	2.462	2.756	3.038	3.396	3.659
30	.256	.683	1.310	1.697	2.042	2.457	2.750	3.030	3.385	3.646
40	.255	.681	1.303	1.684	2.021	2.423	2.704	2.971	3.307	3.551
60	.254	.679	1.296	1.671	2.000	2.390	2.660	2.915	3.232	3.460
120	.254	.677	1.289	1.658	1.980	2.358	2.617	2.860	3.160	3.373
∞	.253	.674	1.282	1.645	1.960	2.326	2.576	2.807	3.090	3.291

Source: This table is adapted from *Biometrika Tables for Statisticians*. Vol. 1. 3rd edition. 1966. by permission of the Biometrika Trustees.

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✓ sum 1-9-92

ATTACHMENT B

COMPACTION TESTS - INBERG-MILLER ENGINEERS

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Page _1_ of _1_

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: June 14, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 6-14-90   Tests By: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION
____ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x__ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp.
1	Wind blow-out area	1.0' above initial grade	Light brown, silty, SAND	5.8	99.3	4.5	103.8	96
2	"	"	"	5.5	100.0	4.5	103.8	96
3	"	"	"	4.7	101.3	4.5	103.8	98

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15,

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 9-14 Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Com
250	6700N 8875E Area 2	Finish Interim Cover Grade	Brown Silty Sand	1.4	103.5	11.3	110.6	94
251	Sand Cone correlation # 250	"	"	1.1	103.9	11.3	110.6	94
252	6700N 8500E Area 2	"	"	1.9	108.5	11.3	110.6	98
253	6700N 8300E Area 2	"	"	1.2	110.8	11.3	110.6	100
254	6500N 8500E Area 2	"	"	1.5	111.0	11.3	110.6	100
255	6300N 8700E Area 2	"	"	1.0	110.5	11.3	110.6	100
256	Sand Cone correlation # 255	"	"	1.3	110.0	11.3	110.6	99

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15, 1

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 9-14   Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
257	6300N 8400E Area 2	Finish Interim Cover Grade	Brown Silty Sand	1.0	104.0	11.3	110.6	[illegible]
258	6300N 8000E Area 2	"	"	1.9	105.5	11.3	110.6	95
259	Sand Cone corr-elation # 258	"	"	2.2	105.8	11.3	110.6	96
260	6100N 8100E Area 2	"	"	1.9	109.0	11.3	110.6	99
261	6100N 8400E Area 2	"	"	1.3	101.3	11.3	110.6	92
262	Sand Cone corr-elation # 261	"	"	1.1	101.0	11.3	110.6	91

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project:	Split Rock Millsite Tailings Reclamation	Date:	September 15, 19

To:

Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 9-14   Tests by: WAU

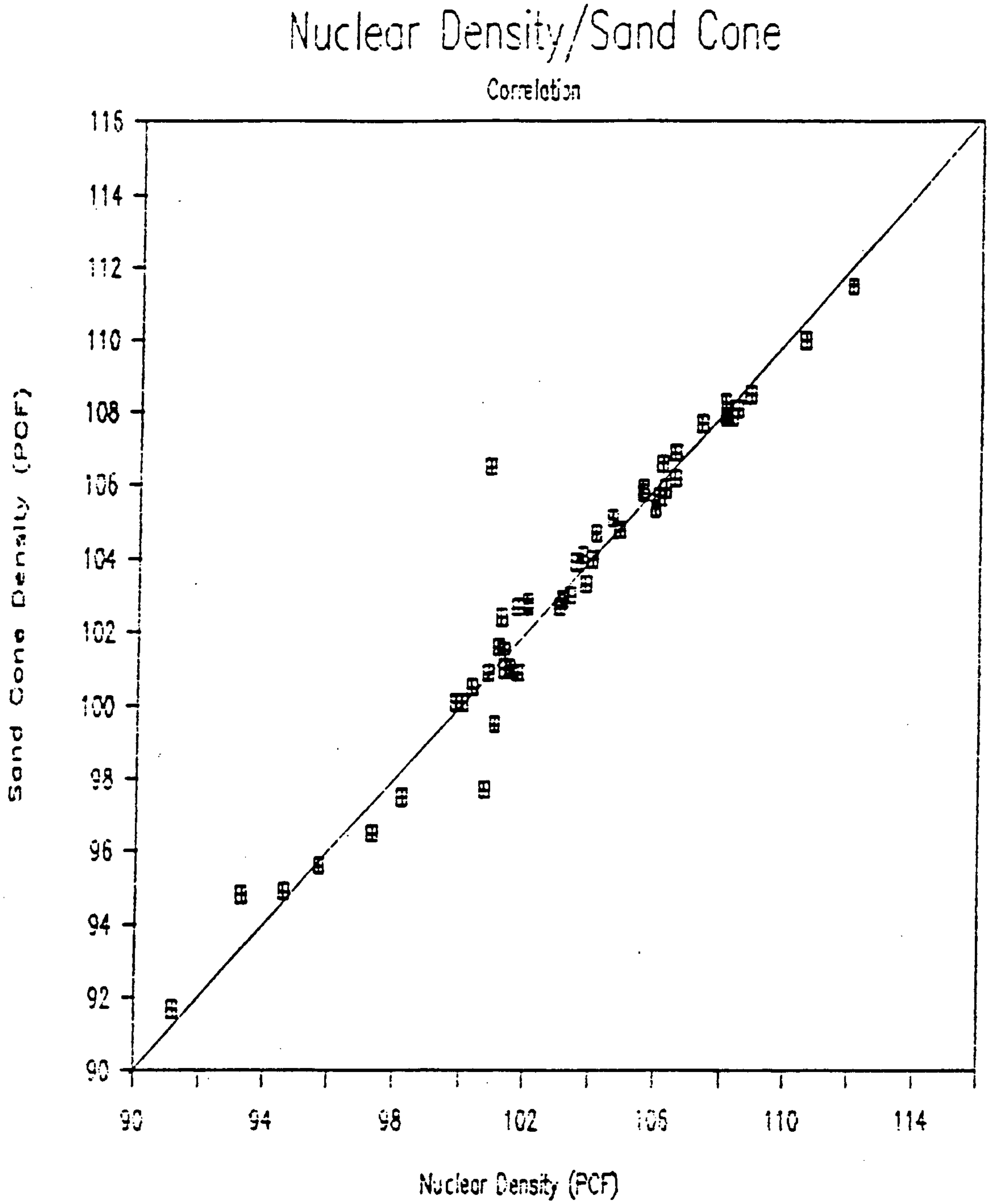
TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
263	6100N 8600E Area 2	Finish Interim Cover Grade	Brown Silty Sand	1.6	107.3	11.3	110.6	97
264	6100N 9000E Area 2	"	"	1.9	112.0	11.3	110.6	101
265	Sand Cone correlation # 264	"	"	1.5	111.5	11.3	110.6	101
266	6100N 9200E Area 2	"	"	1.4	106.0	11.3	110.6	96

~~K-32~~
J-32


Nuclear Density/Sand Cone
Correlation
Sand Cone Density (PCF)
116
114
112
110
108
106
104
102
100
98
96
94
92
90
90
94
98
102
106
110
114
Nuclear Density (PCF)

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J-33

Western Nuclear, Inc.
Split Rock Millsite - Tailings Reclamation
79.1-RM

[illegible]clear Moisture-Density Gauge/ Sand Cone Density Correlation

Corr-elation No.	Test Numbers	Nuclear Density (PCF)	Sand Cone Density (PCF)
1	9 & 10	100.8	106.5
2	19 & 20	101.0	99.5
3	21 & 22	101.7	100.9
4	24 & 25	93.3	94.8
5	38 & 39	101.1	101.6
6	45 & 46	101.2	102.4
7	49 & 50	91.2	91.7
8	53 & 54	100.7	97.7
9	57 & 58	108.2	107.9
10	61 & 62	98.2	97.5
11	68 & 69	102.0	102.7
12	72 & 73	101.7	102.7
13	88 & 89	104.6	105.1
14	91 & 92	95.7	95.6
15	94 & 95	94.6	94.9
16	117 & 118	108.1	107.9
17	120 & 121	102.0	102.8
18	142 & 143	104.1	104.7
19	145 & 146	103.1	102.9
20	147 & 148	103.7	104.1
21	154 & 155	103.8	103.3
22	158 & 159	104.0	104.0
23	160 & 161	107.3	107.7
24	163 & 164	108.0	108.3
25	167 & 168	108.4	108.1
26	170 & 171	106.2	105.9
27	173 & 174	103.3	103.0
28	176 & 177	106.1	106.6
29	179 & 180	105.9	105.4
30	185 & 186	106.5	106.9
31	192 & 193	108.0	107.9
32	196 & 197	99.8	100.1
33	198 & 199	103.0	102.7
34	200 & 201	97.3	96.5
35	205 & 206	106.0	105.7
36	208 & 209	100.8	100.9
37	211 & 212	108.8	108.5
38	214 & 215	100.0	100.1
39	217 & 219	101.5	101.0

Through 9-15-90

estern Nuclear, Inc.
Split Rock Millsite - Tailings Reclamation
4779.1-RM

Nuclear Moisture-Density Gauge/
Sand Cone Density Correlation

Correlation No.	Test Numbers	Nuclear Density (PCF)	Sand Cone Density (PCF)
40	226 & 227	104.8	104.8
41	231 & 232	105.5	105.9
42	237 & 238	100.3	100.5
43	241 & 242	106.5	106.2
44	245 & 246	101.3	101.5
45	250 & 251	103.5	103.9
46	255 & 256	110.5	110.0
47	258 & 259	105.5	105.8
48	261 & 262	101.3	101.0
49	264 & 265	112.0	111.5

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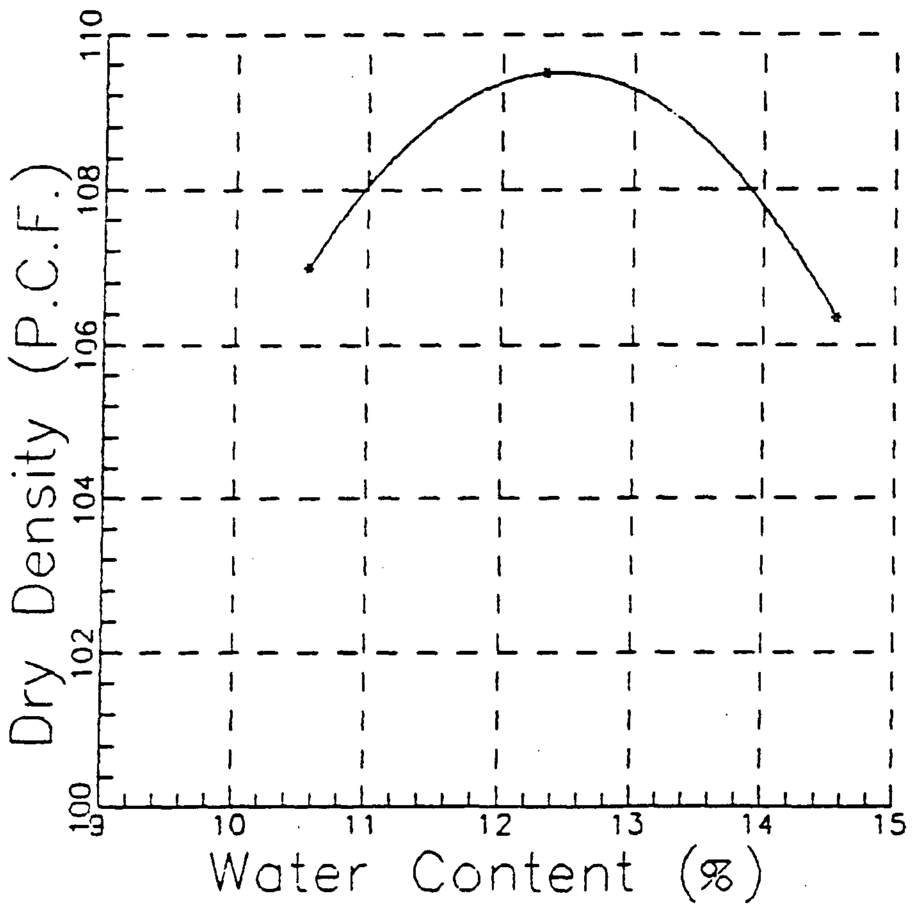
Moisture-Density Analysis
ASTM D-698

Project: Tailings Reclamation
Split Rock Millsite
Client: Western Nuclear, Inc.

Job No.: 4779.1 RM
Date: 9-13-90
Max. Dry Dens.: 109.5
Opt. Moisture : 12.3



Sample From:
Interim Cover, Area 3
Sample No. 9

Sampled by: WAU
Tech: WAU

Sample Description:
Brown Silty Sand

% passing #200: 7.13%
Plasticity Index: Non Plastic

INBERG-MILLER ENGINEERS

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REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: September 19, 1

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 9-19   Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% C
267	Retest # 201	Finish Interim Cover Grade	Brown Silty Sand	8.8	97.0	11.3	110.6	
268	5750N 8200E Area 2	"	"	7.1	98.0	11.3	110.6	88
269	5800N 8300E Area 2	"	"	4.1	109.5	11.3	110.6	99
270	5700N 8400E Area 2	"	"	5.4	107.3	11.3	110.6	97
271	Sand Cone corr-elation # 270	"	"	5.0	107.6	11.3	110.6	97
272	5700N 8300E Area 2	"	"	3.4	103.0	11.3	110.6	93
273	5700N 8200E Area 2	"	"	3.5	108.3	11.3	110.6	98

~~K-3~~
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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: Septemb 19, 19

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 9-19 Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
274	5700N 8100E Area 2	Finish Interim Cover Grade	Brown Silty Sand	5.3	100.3	11.3	110.6	90
275	Sand Cone correlation # 274	"	"	4.7	102.3	11.3	110.6	92
276	5700N 8000E Area 2	"	"	3.9	109.8	11.3	110.6	99
277	5900N 8100E Area 2	"	"	3.6	104.8	11.3	110.6	95
278	5900N 8200E Area 2	"	"	5.9	106.8	11.3	110.6	96
279	5900N 8300E Area 2	"	"	4.0	107.8	11.3	106.4	97
280	5900N 8400E Area 2	"	"	6.3	104.0	11.3	110.6	94

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 19, 19

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 9-19   Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
281	5800N 8400E Area 2	Finish Interim Cover Grade	Brown Silty Sand	4.5	105.8	11.3	110.6	[illegible]
282	Sand Cone corr-elation # 281	"	"	5.1	104.9	11.3	110.6	95
283	5800N 8300E Area 2	"	"	5.8	107.3	11.3	110.6	97
284	5800N 8200E Area 2	"	"	3.6	112.5	11.3	110.6	101
285	Retest # 268	"	"	4.8	98.8	11.3	110.6	89
286	Retest # 267	"	"	5.7	106.5	11.3	110.6	96

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 19, 19

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 9-19 Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Moist. Cont. %	Dry Dens. pcf	% Comp
287	Retest # 236	Finish Interim Cover Grade	Brown Silty Sand	4.1	104.7	11.3	110.6	95
288	Retest # 285	"	"	5.4	105.3	11.3	110.6	95

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J-40

stern Nuclear, Inc.
lit Rock Millsite - Tailings Reclamation
4779.1-RM

TABLE 1

Nuclear Moisture-Density Gauge/
Sand Cone Density Correlation

Correlation No.	Test Numbers	Nuclear Density (PCF)	Sand Cone Density (PCF)
1	9 & 10	100.8	106.5
2	19 & 20	101.0	99.5
3	21 & 22	101.7	100.9
4	24 & 25	93.3	94.8
5	38 & 39	101.1	101.6
6	45 & 46	101.2	102.4
7	49 & 50	91.2	91.7
8	53 & 54	100.7	97.7
9	57 & 58	108.2	107.9
10	61 & 62	98.2	97.5
11	68 & 69	102.0	102.7
12	72 & 73	101.7	102.7
13	88 & 89	104.6	105.1
14	91 & 92	95.7	95.6
15	94 & 95	94.6	94.9
16	117 & 118	108.1	107.9
17	120 & 121	102.0	102.8
18	142 & 143	104.1	104.7
19	145 & 146	103.1	102.9
20	147 & 148	103.7	104.1
21	154 & 155	103.8	103.3
22	158 & 159	104.0	104.0
23	160 & 161	107.3	107.7
24	163 & 164	108.0	108.3
25	167 & 168	108.4	108.1
26	170 & 171	106.2	105.9
27	173 & 174	103.3	103.0
28	176 & 177	106.1	106.6
29	179 & 180	105.9	105.4
30	185 & 186	106.5	106.9
31	192 & 193	108.0	107.9
32	196 & 197	99.8	100.1
33	198 & 199	103.0	102.7
34	200 & 201	97.3	96.5
35	205 & 206	106.0	105.7
36	208 & 209	100.8	100.9
37	211 & 212	108.8	108.5
38	214 & 215	100.0	100.1
39	217 & 219	101.5	101.0

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jwm
1-9-92

tern Nuclear, Inc.
it Rock Millsite - Tailings Reclamation
/9.1-RM

TABLE 1 - CONT.

Nuclear Moisture-Density Gauge/
Sand Cone Density Correlation

Correlation No.	Test Numbers	Nuclear Density (PCF)	Sand Cone Density (PCF)
40	226 & 227 ✓	104.8	104.8
41	231 & 232 ✓	105.5	105.9
42	237 & 238 ✓	100.3	100.5
43	241 & 242 ✓	106.5	106.2
44	245 & 246 ✓	101.3	101.5
45	250 & 251 ✓	103.5	103.9
46	255 & 256 ✓	110.5	110.0
47	258 & 259 ✓	105.5	105.8
48	261 & 262 ✓	101.3	101.0
49	264 & 265 ✓	112.0	111.5
50	270 & 271 ✓	107.3	107.6
51	274 & 275	100.3	102.3
52	281 & 282	105.8	104.9

Through 9-19-90

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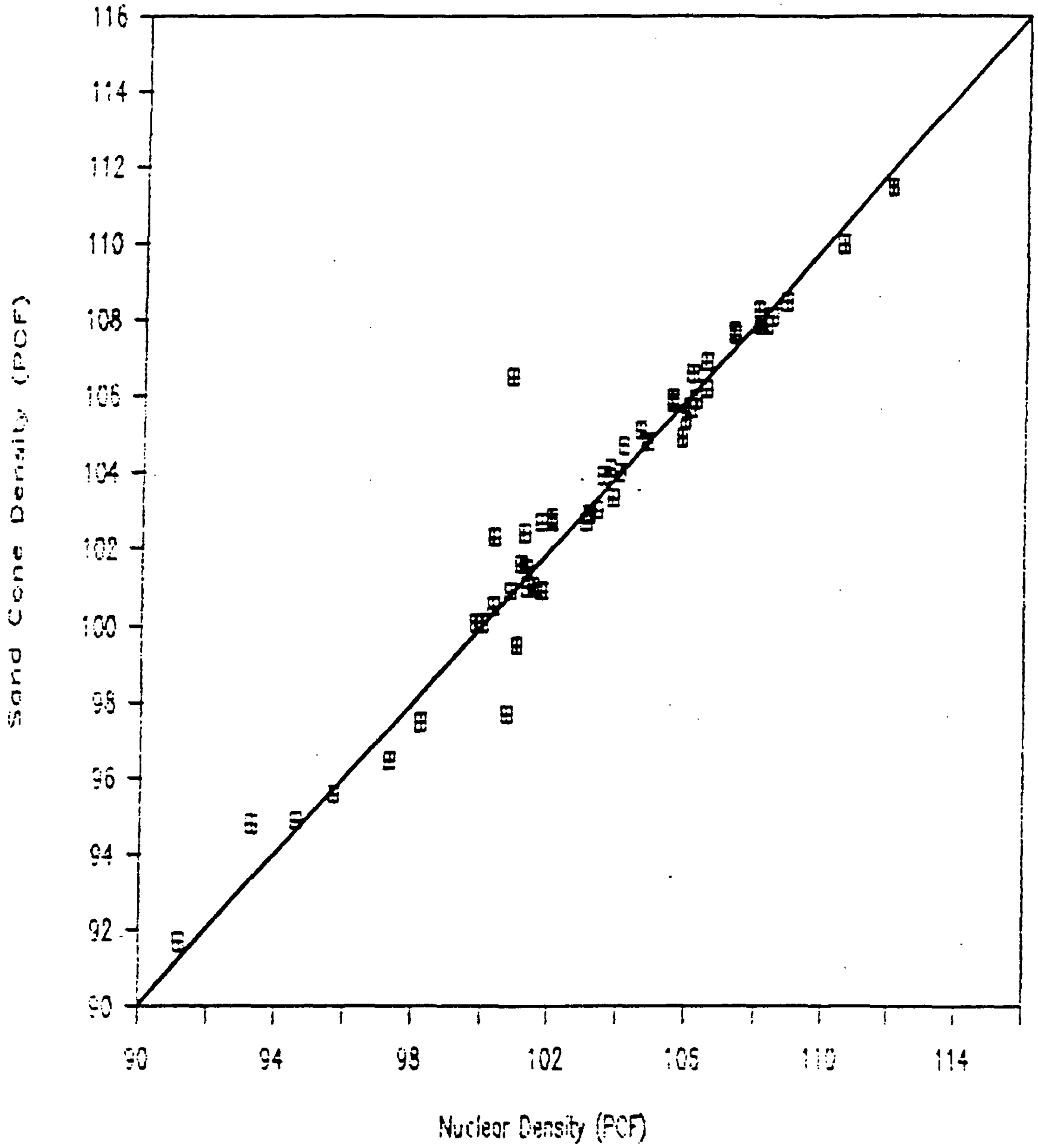
Nuclear Density/Sand Cone

Correlation



~~K-43~~
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Page _1_ of _1

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: June 18, 199

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 6-18-90   Tests By: WAU/RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
____ Sand Cone Method (ASTM D1556)	_x__ Standard Proctor (ASTM D698
_x__ Nuclear Method (ASTM D2922)	____ Modified Proctor (ASTM D1557

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp
4	6000N, 8500E	2.0' above initial grade	Light brown, silty, SAND	4.6*	104.3	4.5	103.8	100
*Speedy Moisture correlation				4.4				
5	5900N, 8300E	"	"	4.9	106.3	4.5	103.8	102

T.44

Max. Dry Dens.: 103.8
Opt. Moisture : 4.5 %
Method: ASTM D-698

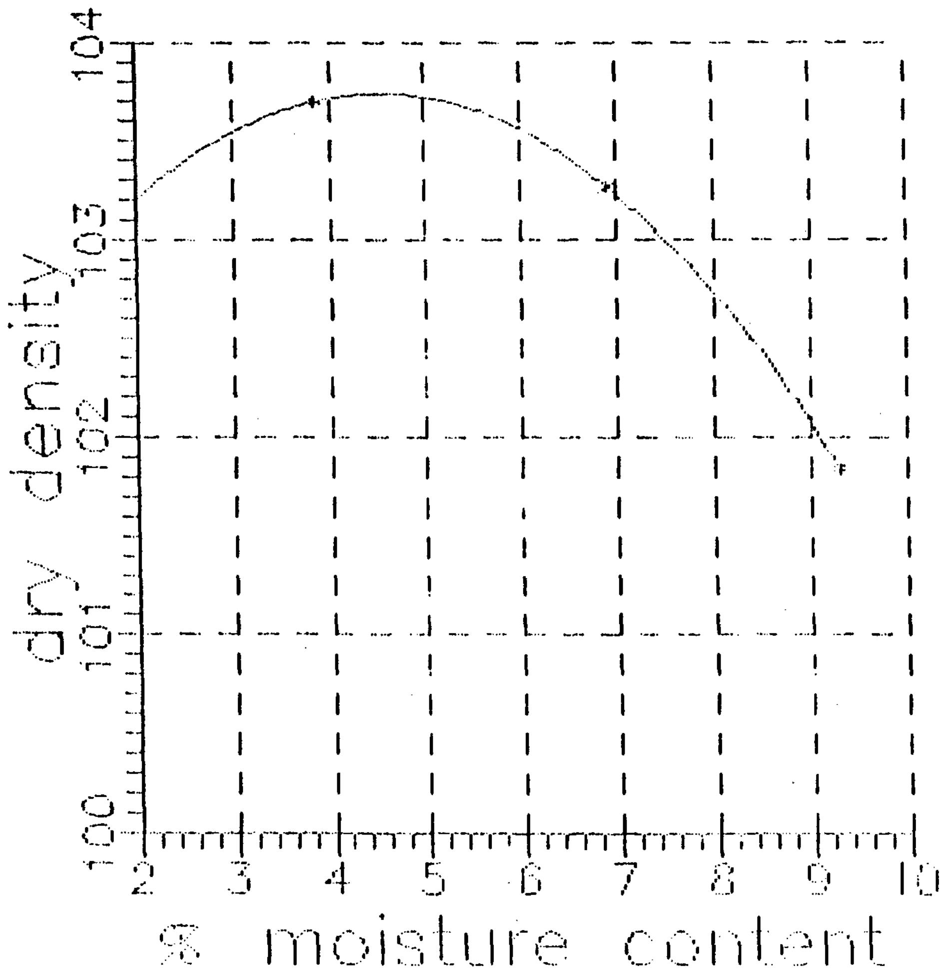
Sampled by: RWA
Tech: RWA

Job No.: 4779.1 RM

Sample From:
Old tailings embankment

Sample Description:
Light brown, silty Sand

Inberg-Miller Engineers



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Page _1_ o

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: June 19, 1

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 6-19-90   Tests By: WAU/R

TEST METHODS:

FIELD DENSITY DETERMINATION
_x__ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x__ Standard Proctor (ASTM D6
____ Modified Proctor (ASTM D15

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	Cc
6	6500N, 8000E	1.0' above initial grade	Light brown, silty, SAND	4.0	88.5	10.2	103.8	8
7	6400N, 8100E	"	"	10.2	83.0	10.2	103.8	8
8	5800N, 8200E	"	"	5.7	87.0	10.2	103.8	8
9	Retest of #7	"	"	5.7+*	100.8	10.2	103.8	9
10**	Retest of #6	"	"	6.8	106.5	10.2	103.8	10

*	Speedy Moisture Correlation	6.8
+	Oven Dry Moisture Correlation	6.8
**	Sand Cone Method	

Item J-46
1-9-92

Max. Dry Dens.: 103.8
Opt. Moisture : 12.2%
Method: ASTM D-698

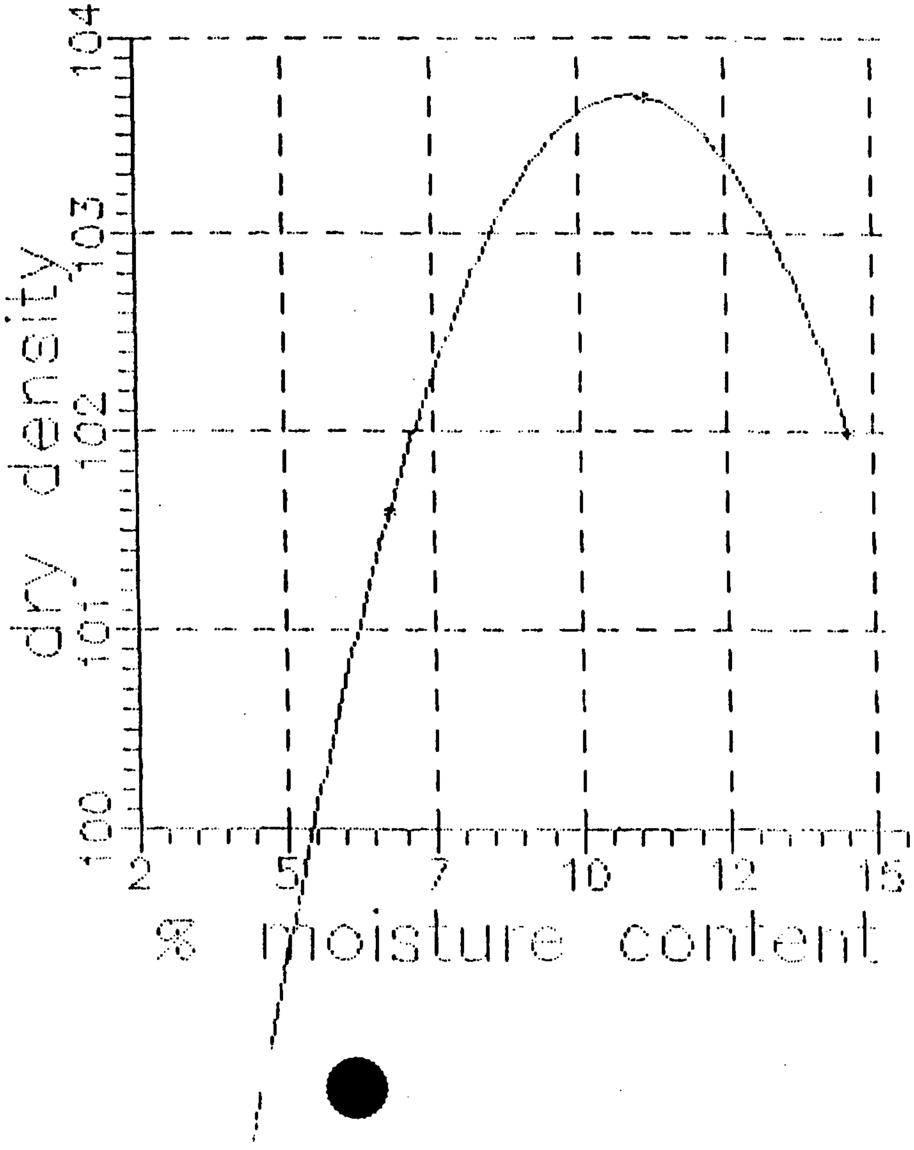
Sampled by: WAL
Tech: WAL

Job No.: 4779.1 RM
Sample From:
Old tailings embankment
Sample No. 2

Sample Description:
Light brown, silty Sand

% passing #200: 6.25
Plasticity Index:
Non-Plastic

Inberg-Miller Engineers



~~K-47~~
J-47

Page _1_ of _

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: June 20, 19

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM Test Date: 6-19-90 Tests By: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
____ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x__ Standard Proctor (ASTM D698
____ Modified Proctor (ASTM D1557

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Com
11	Retest of #8	1.0' above initial grade	Light brown, silty, SAND	5.3	105.4	10.2	103.8	101
12	6500N, 7800E	2.0' above initial grade	"	4.1	97.5	10.2	103.8	94
13	5600N, 7900E	"	"	5.1	104.3	10.2	103.8	100
14	6400N, 8080E	"	"	5.8	104.0	10.2	103.8	100
15	6400N, 8000E	"	"	3.9	92.9	10.2	103.8	90
16	6600N, 8600E	"	"	8.0	106.5	10.2	103.8	10[illegible]

\+ Oven Dry Moisture Correlation 6.8
** Sand Cone Method

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INBERG-MILLER ENGINEERS
124 EAST MAIN STREET RIVERTON, WYOMING 82501-4397 307-856-8136

Page 1 of 3

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: June 21, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM Test Date: As Noted Tests By: WAU/RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
___ Sand Cone Method (ASTM D1556)
x Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
x Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp.
June 14, 1990								
1	Wind blow-out area	1.0' above initial grade	Light brown, silty, SAND	5.8	99.3	4.5	103.8	96
2	"	"	"	5.5	100.0	4.5	103.8	96
3	"	"	"	4.7	101.3	4.5	103.8	98
June 18, 1990								
4	6000N, 8500E	2.0' above initial grade	Light brown, silty, SAND	4.6*	104.3	4.5	103.8	100
*Speedy Moisture correlation				4.4				
5	5900N, 8300E	"	"	4.9	106.3	4.5	103.8	102

~~K-49~~ J-49

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: June 21, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: As Noted   Tests By: WAU/RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
x Sand Cone Method (ASTM D1556)	x Standard Proctor (ASTM D698)
x Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp.
June 19, 1990								
6	6500N, 8000E	1.0' above initial grade	Light brown, silty, SAND	4.0	88.5	10.2	103.8	85
7	6400N, 8100E	"	"	10.2	83.0	10.2	103.8	80
8	5800N, 8200E	"	"	5.7	87.0	10.2	103.8	84
9	Retest of #7	"	"	5.7+*	100.8	10.2	103.8	97
10**	Retest of #9	"	"	6.8	106.5	10.2	103.8	103

*	Speedy Moisture Correlation	6.8
+	Oven Dry Moisture Correlation	6.8
**	Sand Cone Method	

1-9-92

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INBERG-MILLER ENGINEERS

124 EAST MAIN STREET RIVERTON, WYOMING 82501-4397 307-856-8136

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REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: June 21, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM Test Date: As Noted Tests By: WAU/RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
- ____ Sand Cone Method (ASTM D1556)
- x Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
- x Standard Proctor (ASTM D698)
- ____ Modified Proctor (ASTM D1557)

TEST RESULT

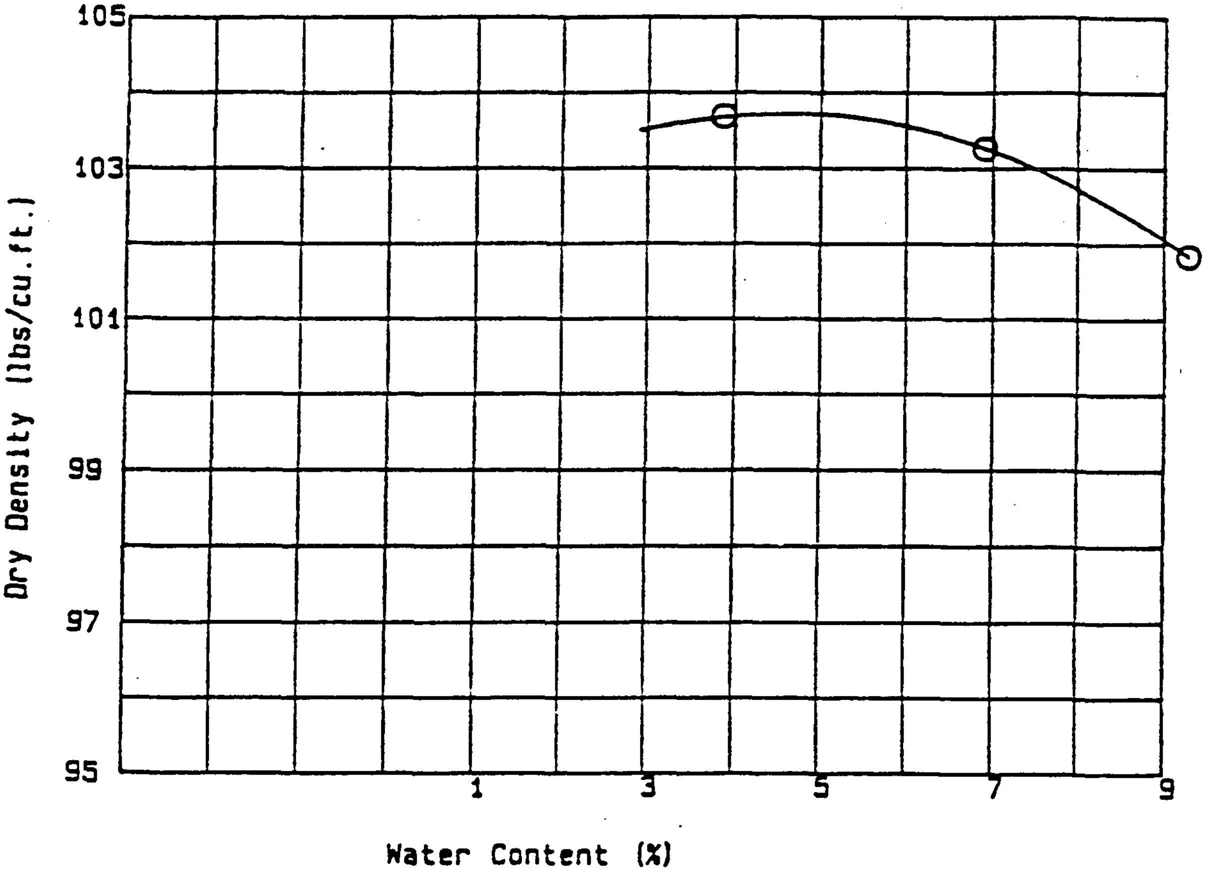
Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp.
June 20, 1990								
11	Retest of #8	1.0' above initial grade	Light brown, silty, SAND	5.3	105.4	10.2	103.8	101
12	6500N, 7800E	2.0' above initial grade	"	4.1	97.5	10.2	103.8	94
13	5600N, 7900E	"	"	5.1	104.3	10.2	103.8	100
14	6400N, 8080E	"	"	5.8	104.0	10.2	103.8	100
15	6400N, 8000E	"	"	3.9	92.9	10.2	103.8	90
16	6600N, 8600E	"	"	8.0	106.5	10.2	103.8	103

~~K-5~~
J-51

MOISTURE-DENSITY ANALYSIS

Project: TAILINGS RECLAMATION
Job No.: 4779.1 RM
Client: WNI

Test Date: 6/18/90
Tested By: RWA
Test Method: ASTM D-698



Soil Description: LIGHT BROWN SILTY SAND

% passing #200 sieve: 7.58

Liquid Limit:
Plasticity Index: NON PLASTIC

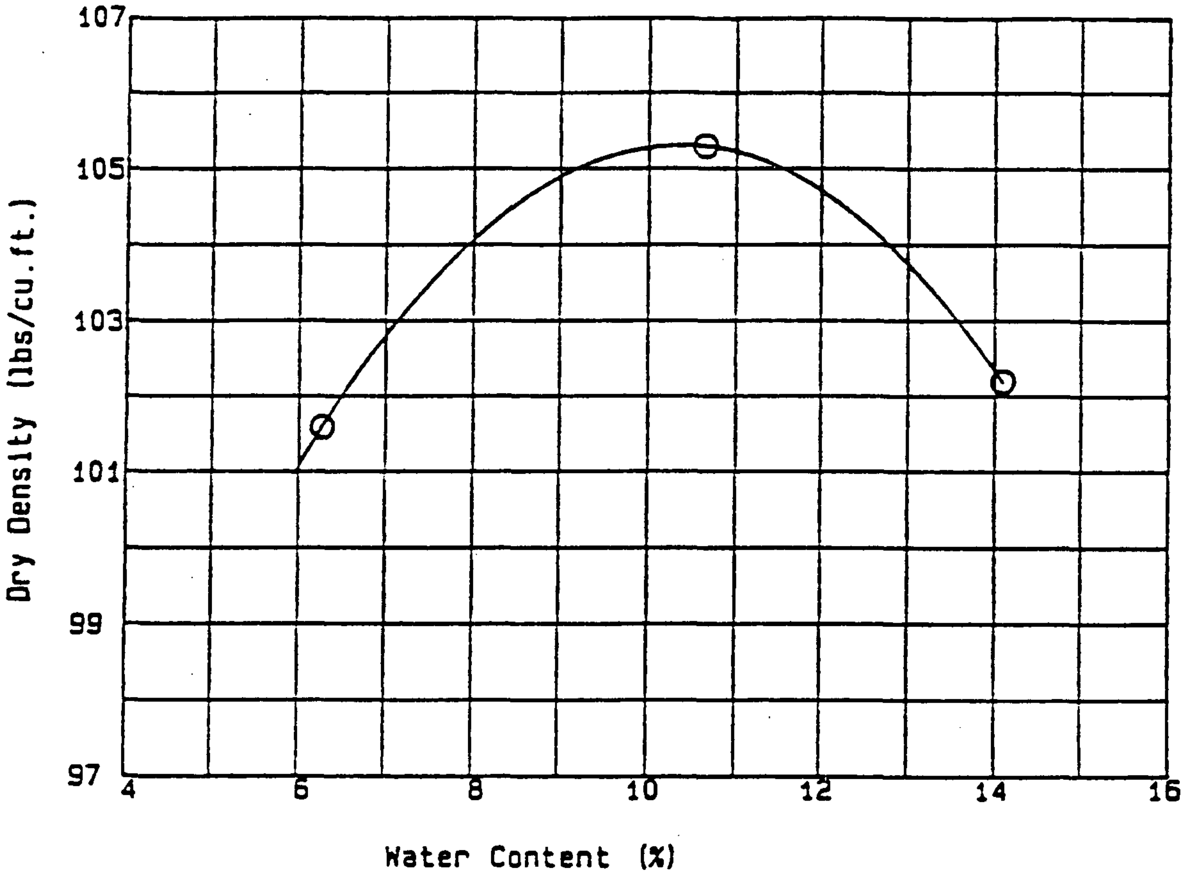
Sample No.: 1
Sampled By: RWA
Source: TAILINGS DIKE

Optimum Water Content: 5.0 %
Max. Dry Density: 103.8 lbs/cu.ft.

K-82
1-9-92
J-52

MOISTURE-DENSITY ANALYSIS

Project:	TAILINGS RECLAMATION	Test Date:	6/19/90
Job No.:	4779.1 RM	Tested By:	WAU
Client:	WNI	Test Method:	ASTM D-698



Soil Description: LIGHT BROWN SILTY FINE SAND

Sample No.: 2

Sampled By: WAU

Source: TAILINGS DIKE

% passing #200 sieve: 6.25

Liquid Limit:

Plasticity Index: NON-PLASTIC

Optimum Water Content: 10.2 %

Max. Dry Density: 105.4 lbs/cu.ft.

~~K-53~~
J-53

Page _1_ of _1__

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: June 27, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 6-26-90   Tests By: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
____ Sand Cone Method (ASTM D1556)	__x_ Standard Proctor (ASTM D698)
_x__ Nuclear Method (ASTM D2922)	____ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp
17	6000N 9400E	finished tailings grade	light brown silty sand	2.6	100.9	12.4	105.8	95
	speedy moisture correlation			2.9				
18	8400N 8200E	finished tailings grade	light brown silty sand	4.4	104.8	12.4	105.8	99
	speedy moisture correlation			3.5				
18a	Sand cone correlation w/speedy moisture			6.4	99.5	12.4	105.8	94
19	8300N 8600E	finished tailings grade	light brown silty sand	5.9	101.0	12.4	105.8	95
	speedy moisture correlation			6.4				

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v Jun
1-9-92

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REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: June 28, 199C

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: As noted   Tests By: WAU/RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x__ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
__x_ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Com
6-26-90								
17	6000N & 9400E	Finished tailings grade	Light Brown, Silty, Fine Sand	2.6*	100.9	12.4	105.8	95
	*speedy moisture correlation			2.9				
18	8400N & 8200E	"	"	4.4*	104.8	12.4	105.8	99
	*speedy moisture correlation			3.5				
19	8300N & 8600E	"	"	5.9	101.0	12.4	105.8	95
20	Sand Cone corr-ellation #19	"	"	6.4	99.5	12.4	105.8	94

~~K-55~~
J-55

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: June 28, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM Test Date: As noted Tests By: WAU/RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x__ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method · (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
__x_ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557

TEST RESULT

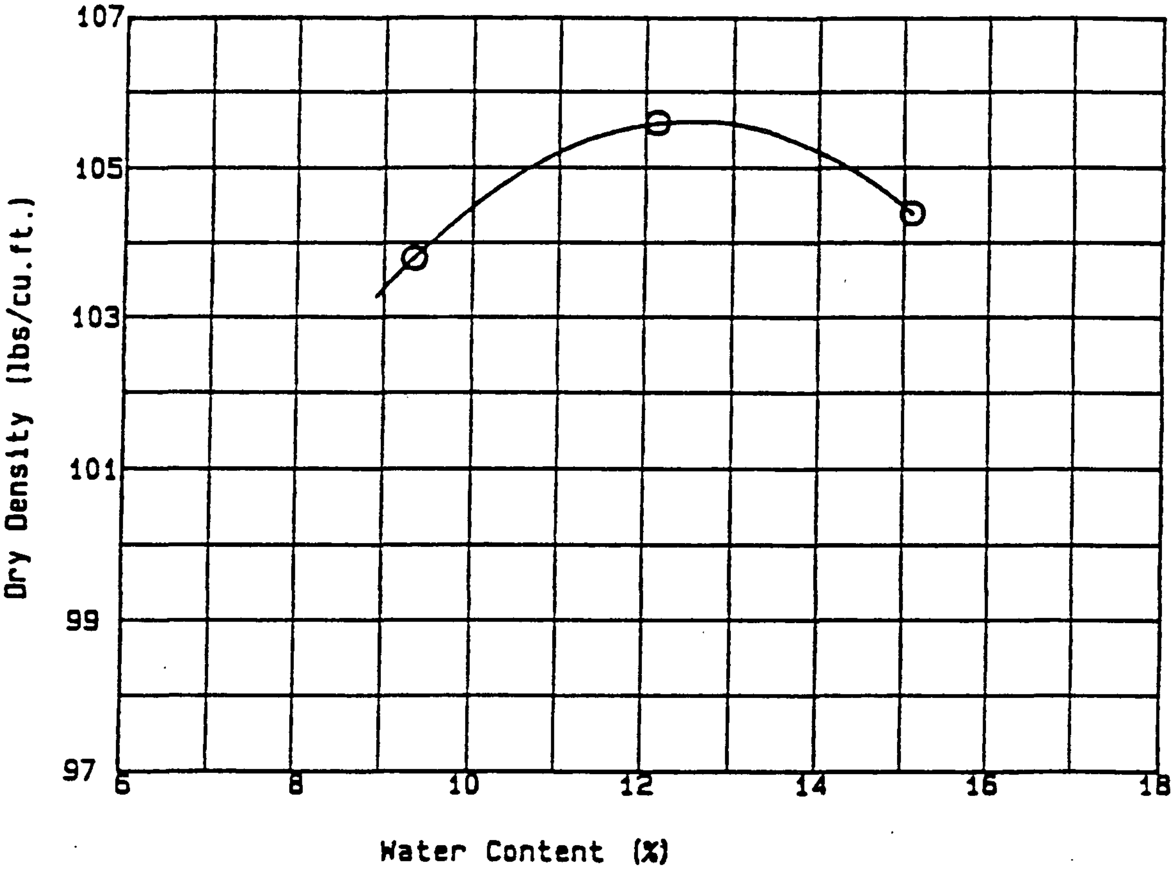
Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	C
6-27-90								
21	8500N & 8200E	3 Feet above initial grade	Light Brown, Silty Fine Sand	3.3	101.7	12.4	105.8	96
22	Sand Cone corr-ellation #21	"	"	3.8	100.9	12.4	105.8	95
23	8500N & 8500E	"	"	4.7	101.8	12.4	105.8	96

~~K-56~~ J-56
✓ [illegible]
1-9-92

MOISTURE-DENSITY ANALYSIS

Project: TAILINGS RELCLAMATION
Job No.: 4779.1 RM
Client: WNI

Test Date: 6/25/90
Tested By: WAU
Test Method: ASTM D-698



Soil Description: LIGHT BROWN
SILTY FINE SAND

% passing #200 sieve: 8.09

Liquid Limit:
Plasticity Index: NON-PLASTIC

Sample No.: 3
Sampled By: WAU
Source: TAILINGS DIKE

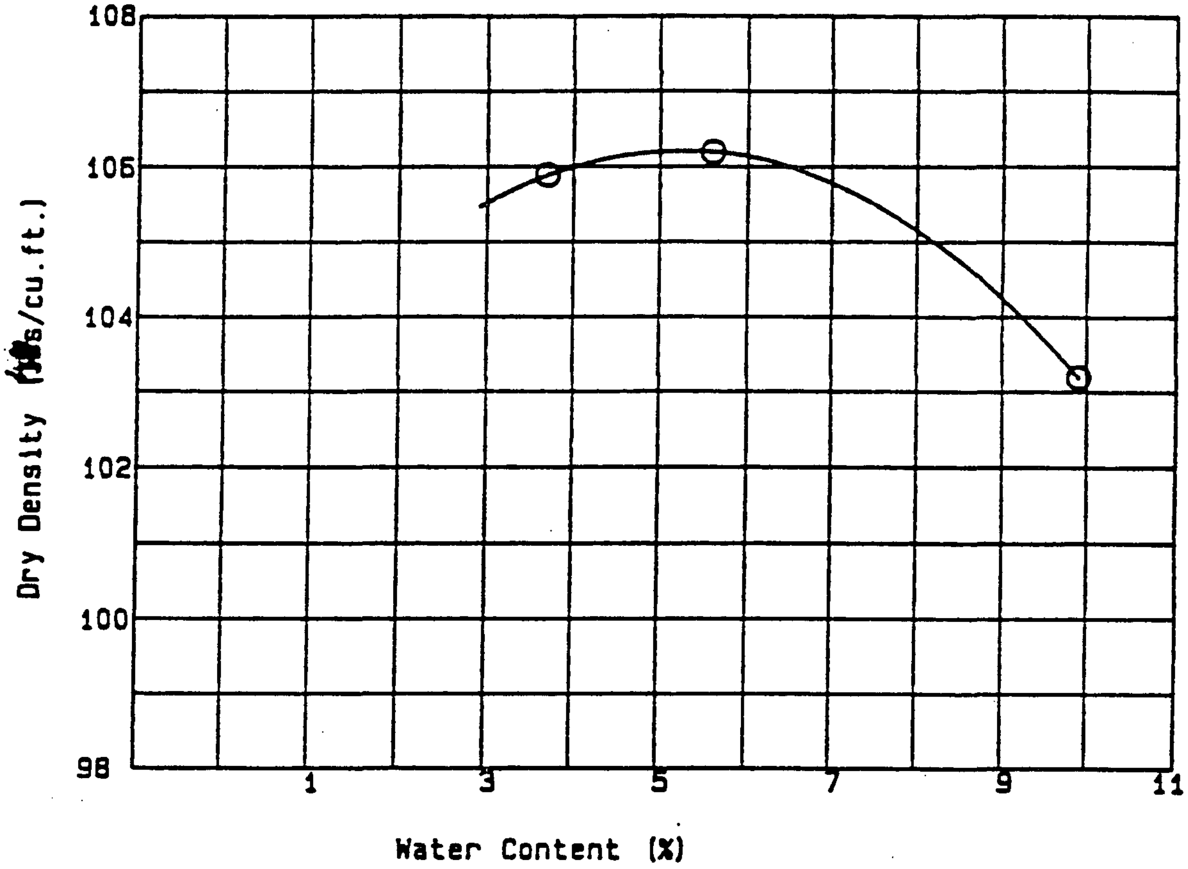
Optimum Water Content: 12.6 %
Max. Dry Density: 105.8 lbs/cu.ft.

~~K57~~
J-57

MOISTURE-DENSITY ANALYSIS

Project: TAILINGS RECLAMATION
Job No.: 4779.1 RM
Client: WNI

Test Date: 6/28/90
Tested By: RWA
Test Method: ASTM D-698



Soil Description: LIGHT BROWN
SILTY FIND SAND

% passing #200 sieve: 4.07

Liquid Limit:
Plasticity Index: NON-PLASTIC

Sample No.: 4
Sampled By: RWA
Source: TAILINGS DIKE

Optimum Water Content: 5.2 %
Max. Dry Density: 106.4 lbs/cu.ft.

~~K-58~~ J-58
1-9-92

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: July 5, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM Test Date: 7-3 Tests By: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x__ Sand Cone Method (ASTM D1556)	__x_ Standard Proctor (ASTM D698)
_x__ Nuclear Method (ASTM D2922)	____ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp
7-3-90								
24	8400N 8300E	2' below tailings grade	Light Brown, Silty, Fine Sand	2.7	93.3	12.4	103.8	90
*speedy moisture correlation				5.0				
25	Sand Cone correlation # 24	"	"	5.0	94.8	12.4	103.8	91
26	8400N & 8800E	"	"	3.2*	106.8	12.4	105.8	100
*speedy moisture correlation				3.6				
27	8800N & 8200E	"	"	2.5*	106.8	12.4	105.8	100
*speedy moisture correlation				1.4				

~~K-59~~
J-59

Page _2_ of .

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: July 9, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM Test Date: 7-3 Tests By: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
____ Sand Cone Method (ASTM D1556)	__x_ Standard Proctor (ASTM D698
_x__ Nuclear Method (ASTM D2922)	____ Modified Proctor (ASTM D155

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	C
7-3-90								
28	6500N & 8200E	3 Feet above initial grade	Black Silty Fine Sand	4.4	95.1	12.4	105.8	90
	*speedy moisture correlation			4.6				
29	6500N & 8900E	"	"	2.7	98.7	12.4	105.8	93

~~K-60~~
J-60

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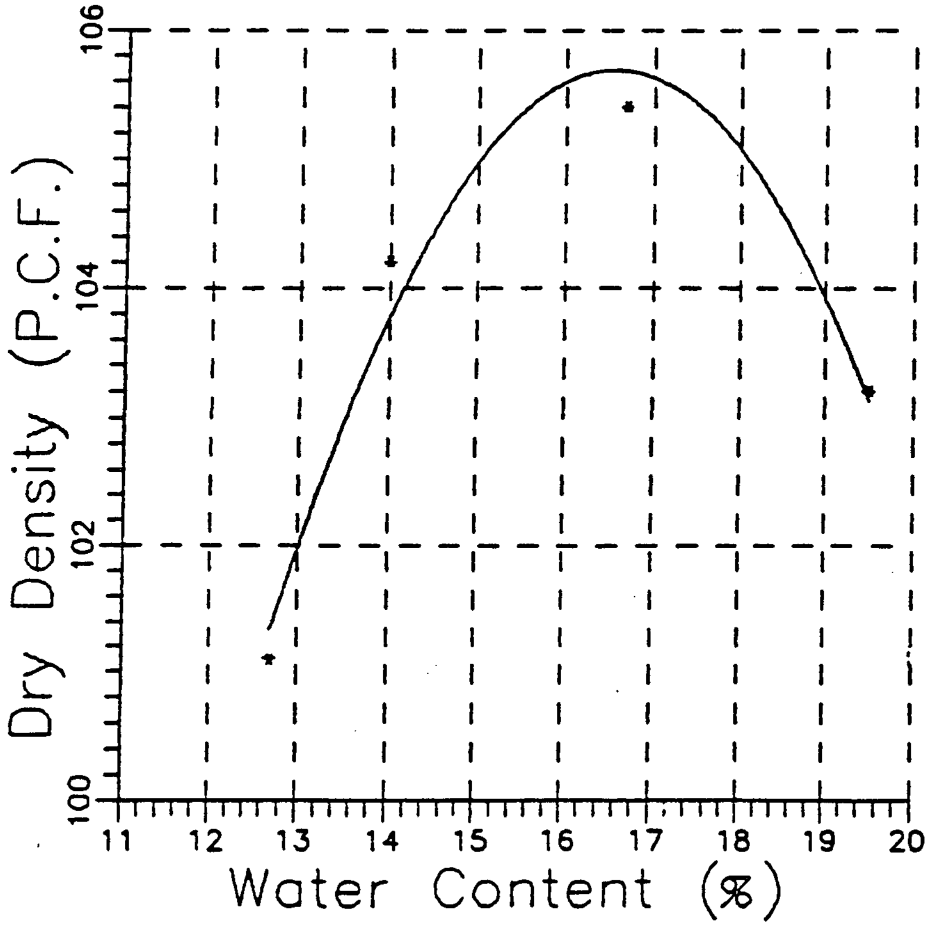
1-9-92

Moisture-Density Analysis
ASTM D-698

Project: Tailings Reclamation
Split Rock Millsite
Client: Western Nuclear, Inc.

Job No.: 4779.1 RM

Max. Dry Dens.: 105.7
Opt. Moisture : 16.5



Sample From:
6500N, 8770E
Sample No. 5

Sampled by: RWA
Tech: RWA

Sample Description:
Dark grey, Silty Fine Sand

% passing #200: 9.3
Plasticity Index:
Non-Plastic

INBERG-MILLER ENGINEERS

~~K61~~
J-61

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REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: July 13, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 7-9   Tests By: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x__ Sand Cone Method (ASTM D1556)	__x_ Standard Proctor (ASTM D698)
_x__ Nuclear Method (ASTM D2922)	____ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp
30	8400N 9210E	3' above initial grade	Light Brown Silty Sand	5.3*	98	12.4	105.8	93
	*speedy moisture correlation			5.0				
31	8350N 9200E	"	"	4.8*	104.8	"	"	99
	*speedy moisture correlation			5.2				
32	8400N 9500E	"	"	3.7*	97.8	"	"	92
	*speedy moisture correlation			3.8				
33	8100N 10000E	5' above initial grade	"	3.2*	111.8	"	"	106
	*speedy moisture correlation			3.8				
34	6900N 8600E	final grade	"	3.5	95.5	"	"	90

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✓ sum
1-992

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: July 13, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 7-9   Tests By: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x__ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
__x_ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557)

TEST RESULT

est No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp
35	7000N 8800E	2' above initial grade	Light Brown Silty Sand	5.3*	94.8	12.4	105.8	90
	*speedy moisture correlation			5.4				
36	6800N 8600E	1' above initial grade	"	2.5	99.5	"	"	94
	*speedy moisture correlation			2.6				
37	6900N 8800E	"	"	2.0	100.5	"	"	95
	*speedy moisture correlation			2.2				
38	8650N 9000E	"	"	3.3	101.1	"	"	96
39	Sand cone correlation #38	"	"	2.7	101.6	"	"	96

~~K-65~~
J-63

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: July 13, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM Test Date: 7-10 Tests By: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
____ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
__x_ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp
7-10-90								
40	8700N 9300E	1' above initial grade	Light Brown Silty Sand	1.4*	102.0	12.4	105.8	96

*speedy moisture correlation 2.9

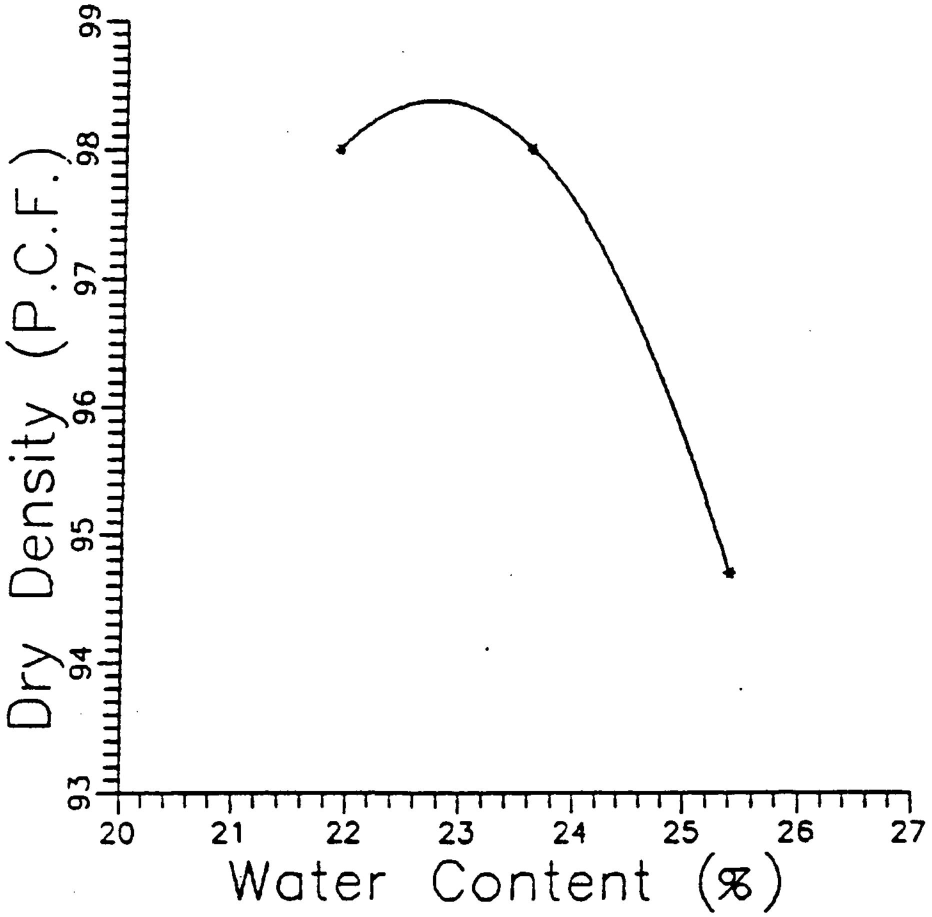
✓ ~~K.64~~ J-64
1-9-92

Moisture-Density Analysis
ASTM D-698

Project: Tailings Reclamation
Split Rock Millsite
Client: Western Nuclear, Inc.

Job No.: 4779.1 RM

Max. Dry Dens.: 98.4
Opt. Moisture : 22.6



Sample From:
6400N, 9700E
Sample No. 5

Sampled by: RWA
Tech: RWA

Sample Description:
Dark grey, Silty Fine Sand

% passing #200: 48.1
Plasticity Index: 17.0

INBERG-MILLER ENGINEERS

~~K-65~~
J-65

Page _1_ of _2__

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: July 20, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 7-16-90   Tests By: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
____ Sand Cone Method (ASTM D1556)	__x_ Standard Proctor (ASTM D698)
_x__ Nuclear Method (ASTM D2922)	____ Modified Proctor (ASTM D1557

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Com
41	7900N 9600E	3'above initial grade	Light Brown Silty Sand	5.2	101.4	12.4	105.8	96
speedy moisture correlation				5.8				
42	7900N 4800E	4'above initial grade	Light Brown Silty Sand	5.9	98.5	12.4	105.8	93
speedy moisture correlation				5.6				
43	7800N 9600E	final grade	Light Brown Silty Sand	5.7	98.8	12.4	105.8	93
speedy moisture correlation				7.0				
44	7600N 9630E	final grade	"	4.2	99.7	12.4	105.8	9
speedy moisture correlation				5.4				

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1-9-92

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: July 20, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 7-16-90   Tests By: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
____ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
__x_ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Com
45	7500N 9800N	final grade	Light Brown Silty Sand	6.8	101.2	12.4	105.8	96
46	Sand Cone correlation #45	"	"	6.3	102.4	12.4	105.8	97

~~X-67~~
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Page _1_ of _6__

FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: July 27, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 7-25   Tests By: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x__ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
__x_ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp
47	8500N 9300E	Finish tailings grade	Light Brown Silty Sand	4.7	101.5	12.4	106.8	95
48	8400N 9310E	"	"	6.3	96.5	"	"	90
49	8400N 9500E	"	Dark Grey Silty fine Sand	9.7	91.2	22.6	98.4	93
50	Sand cone corr-elation # 49	"	"	8.4	91.7	22.6	98.4	93
51	8600N 9500E	"	Light Brown Silty Sand	3.3	103.5	12.4	106.8	97
52	8600N 9400E	"	"	4.1	100.7	"	"	9

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jwm
1-9-92

Page _2_ of _6_

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: July 27, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 7-25   Tests By: RWA/WAL

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp
53	8500N 9000E	Final tailings grade	Light Grey Silty Sand	7.1	100.7	12.4	106.8	94
54	Sand cone corr-elation # 53	"	"	6.2	97.7	"	"	91
55	5400N 7700E	"	Light Brown Silty Sand	4.9	103.5	"	"	97
56	5500N 7680E	"	"	4.4	104.7	"	"	98
57	5600N 7400E	"	"	4.2	108.2	"	"	101
58	Sand cone corr-elation # 57	"	"	4.2	107.9	"	"	101

~~K-64~~
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Page _3_ of _

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: July 27, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 7-25   Tests By: RWA/WAU

TEST METHODS:

FIELD DENSITY DETERMINATION
____ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
__x_ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	(Cc
59	5700N 7760E	Final tailings grade	Light Brown Silty Sand	3.5	105.2	12.4	106.8	99
60	5600N 7900E	"	"	2.9	104.9	"	"	98
61	5700N 8000E	"	"	3.3	98.2	"	"	92
62	Sand cone correlation # 61	"	"	3.4	97.5	"	"	91
63	5600N 8200E	1'below tailings grade	"	4.4	97.5	"	"	91
64	5600N 8290E	"	"	4.3	98.5	"	"	92
65	5600N 8370E	Final tailings grade	"	7.5	95.6	"	"	9

✓ 1-9-92 J-K

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: July 27, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 7-25   Tests By: RWA/WAL

TEST METHODS:

FIELD DENSITY DETERMINATION
_x__ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
__x_ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp
66	5700N 8300E	1'below tailings grade	Light Brown Silty Sand	3.4	98.5	12.4	106.8	92
67	5800N 8200E	Final tailings grade	"	4.5	108.9	"	"	102
68	6000N 8300E	"	"	3.3	102.0	"	"	96
69	Sand cone correlation # 68	"	"	3.4	102.7	"	"	96
70	6100N 8400E	"	"	4.2	99.6	"	"	93
71	6145N 8500E	"	"	5.8	101.7	"	"	95
72	6100N 8500E	"	"	5.4	101.7	"	"	95

~~K-7~~
J-71

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: July 26, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 7-26   Tests By: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
____ Sand Cone Method (ASTM D1556)	__x_ Standard Proctor (ASTM D698)
_x__ Nuclear Method (ASTM D2922)	____ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	(C
73	Sand cone correlation # 72	Finish tailings grade	Light Brown Silty Sand	4.0	102.7	12.4	106.8	96
74	6600N 8700E	"	Dark grey Silty fine Sand	6.9	95.0	22.6	98.4	97
75	9200E 6600N	"	"	15.7	87.1	"	"	89
76	9200E 6550N	"	"	19.6	86.1	"	"	88
77	9150E 6550N	"	"	15.7	85.1	"	"	86
78	9900E 7000N	"	Light Brown Silty Sand	6.3	106.6	12.4	106.8	100
79	7600N 9730E	"	"	2.6	105.6	"	"	

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1-9-92 J-%

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: July 27, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82501

Job. No.: 4779.1-RM   Test Date: 7-26   Tests By: RWA/WAU

TEST METHODS:

FIELD DENSITY DETERMINATION
____ Sand Cone Method (ASTM D1556)
_x__ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
__x_ Standard Proctor (ASTM D698)
____ Modified Proctor (ASTM D1557)

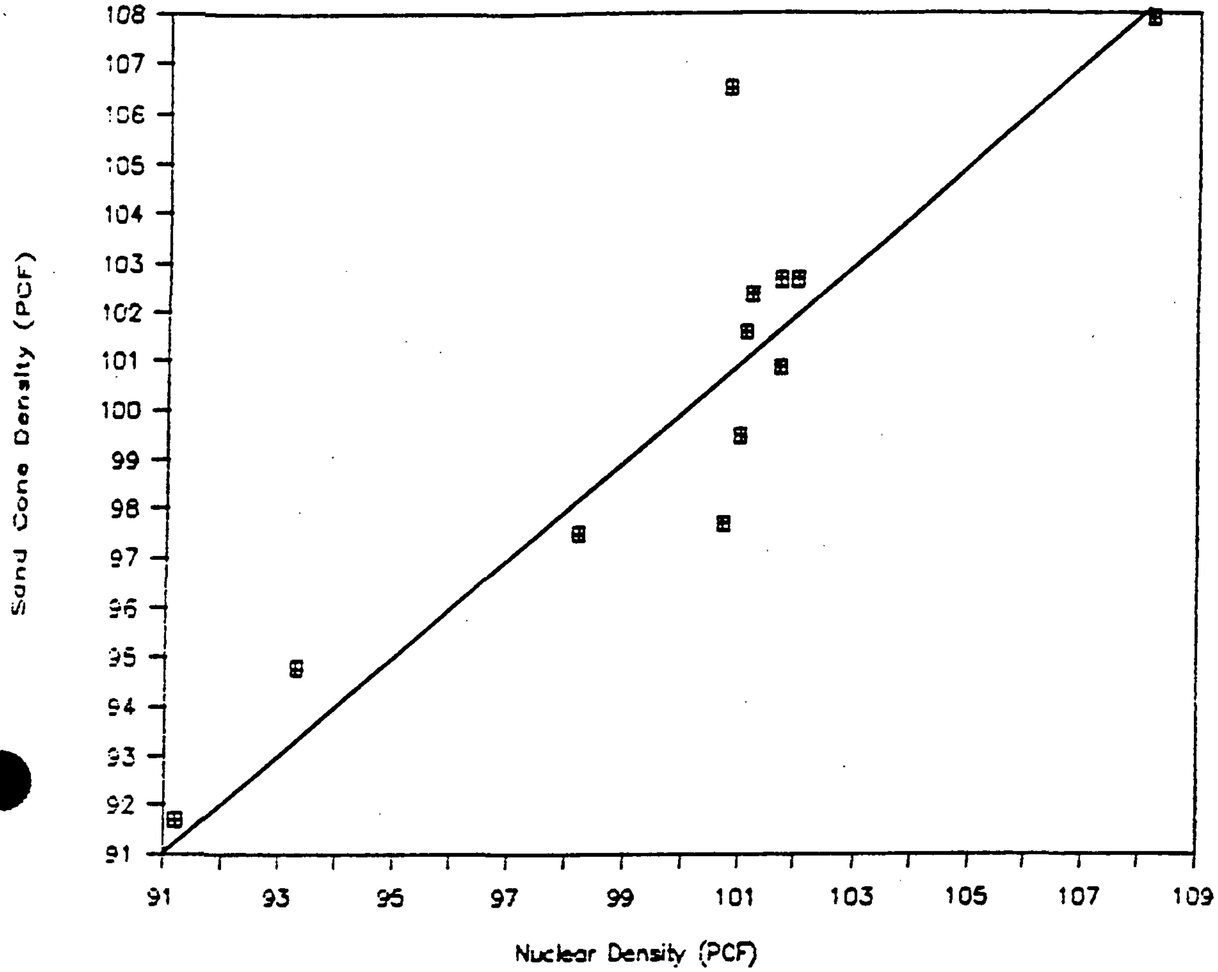
TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist Cont. %	Dry Dens. pcf	Opt. Moist Cont. %	Max. Dry Dens. pcf	% Comp
80	7600N 9530E	Finish Tailings grade	Light Brown Silty Sand	1.9	111.0	12.4	106.8	104
81	7600N 9290E	"	"	3.0	107.5	"	"	100
	speedy moisture correlation			3.2				
82	7500N 9350E	"	"	3.1	108.2	"	"	101
83	7500N 9600E	"	"	4.8	108.2	"	"	101
84	7500N 9800E	"	"	3.3	109.7	"	"	103

~~K-7~~
J-73

Nuclear Density/Sand Cone

Correlation

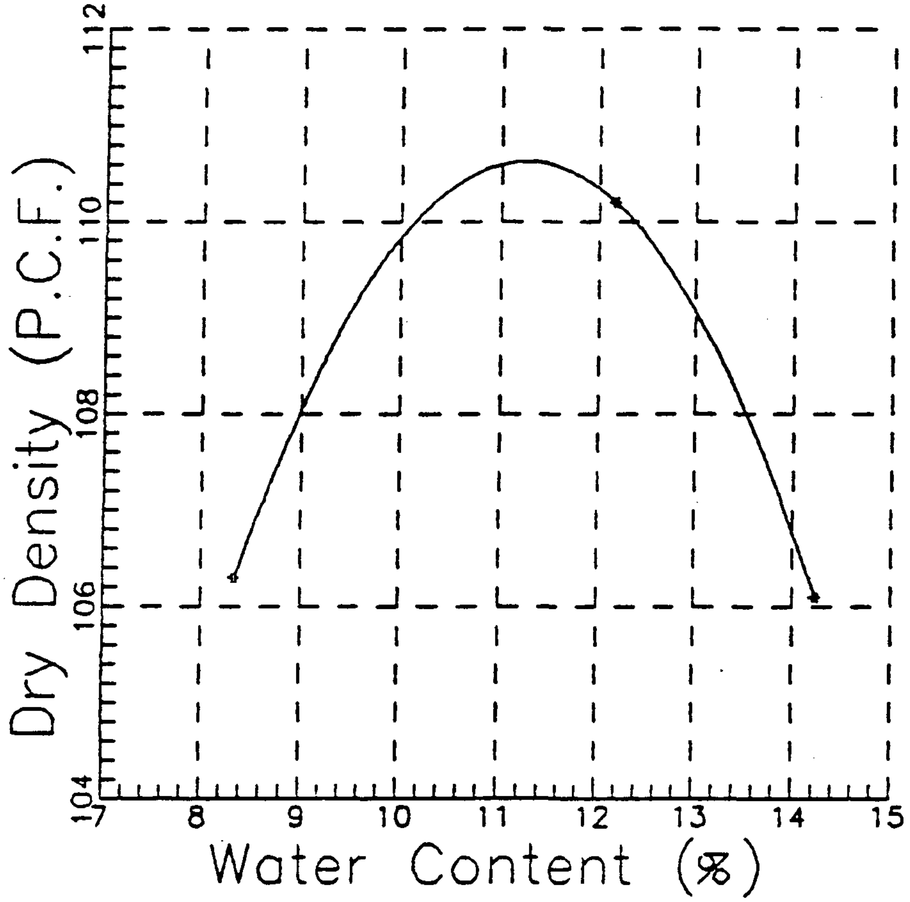


J-74 ~~K1~~
✓ inv.
1-9-92

Moisture–Density Analysis
ASTM D–698

Project: Tailings Reclamation
Split Rock Millsite
Client: Western Nuclear, Inc.

Job No.: 4779.1 RM
Date: 7–26–90
Max. Dry Dens.: 110.6
Opt. Moisture : 11.3



Sample From:
9000N, 11000E
Sample No. 6

Sampled by: RWA
Tech: RWA

Sample Description:
Brown Silty Sand

% passing #200: 13.9
Plasticity Index: Non Plastic

INBERG–MILLER ENGINEERS

~~K-75~~
J-75

Page 1 of 1

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: August 3, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 7-31 Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
- ☒ Sand Cone Method (ASTM D1556)
- ☒ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
- ☒ Standard Proctor (ASTM D698)
- ☐ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Co
85	7400N 9700E	Finish Windblown Grade	Brown Silty Sand	3.4	104.9	11.3	110.6	
86	7400N 9750E	"	"	3.5	102.4	11.3	110.6	93
87	7300N 9650E	"	"	7.5	107.0	11.3	110.6	97
88	7200N 9450E	"	"	3.3	104.6	11.3	110.6	95
89	Sand Cone Correlation # 88	"	"	2.9	105.1	11.3	110.6	95

J-76 [illegible]

Page _1_ of _4_

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: August 10, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 8-7   Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
90	8800N 9700E	1' below Finish Tailings Grade	Dark Gray Very Silty Fine Sand	14.7	100.2	22.6	98.4	102
91	8800N 9800E	"	"	14.9	95.7	22.6	98.4	97
92	Sand Cone correlation # 91	"	"	14.5	95.6	22.6	98.4	97
93	8600N 9230E	"	"	14.2	99.5	22.6	98.4	101
94	8700N 8200E	"	"	15.8	94.6	22.6	98.4	96
95	Sand Cone correlation # 94	"	"	15.3	94.9	22.6	98.4	96

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Page _2_ of _4_

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 10, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 8-7 Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Cq
96	7500N 9400E	Windblown Grade	Brown Silty Sand	2.0	106.3	11.3	110.6	
97	7400N 9400E	"	"	2.7	106.5	11.3	110.6	96
98	7200N 9600E	"	"	4.5	103.1	11.3	110.6	93
99	Sand Cone correlation # 98	"	"	4.7	103.8	11.3	110.6	94
100	7200N 9300E	"	"	5.0	102.5	11.3	110.6	93
101	Retest # 75	Finish Tailings Grade	Dark Gray Very Silty Fine Sand	13.2	95.7	22.6	98.4	97
102	Retest # 76	"	"	3.4	100.0	22.6	98.4	101
103	Retest # 77	"	"	10.7	96.7	22.6	98.4	

J-78 ~~#75~~
min.
1-9-92

Page _3_ of _4_

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 10, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 8-7/8-8   Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
___ [illegible] (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
04	Retest # 99	Finish Windblown Grade	Brown Silty Sand	3.4	106.2	11.3	110.6	96
105	Retest # 100	"	"	4.9	106.1	11.3	110.6	96
106	7750N 9700E	"	"	6.1	104.2	11.3	110.6	94
107	7650N 9700E	"	"	6.7	106.8	11.3	110.6	97
108	7650N 9800E	"	"	6.4	104.0	11.3	110.6	94
109	7750N 9800E	"	"	3.8	103.9	11.3	110.6	94
110	Retest # 106	"	"	2.7	102.2	11.3	110.6	92
111	Retest # 108	"	"	3.8	100.8	11.3	110.6	91
112	Retest # 109	"	"	4.2	103.5	11.3	110.6	94
113	Retest # 111	"	"	4.7	104.8	11.3	110.6	95

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 10, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 8-7/8-8   Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

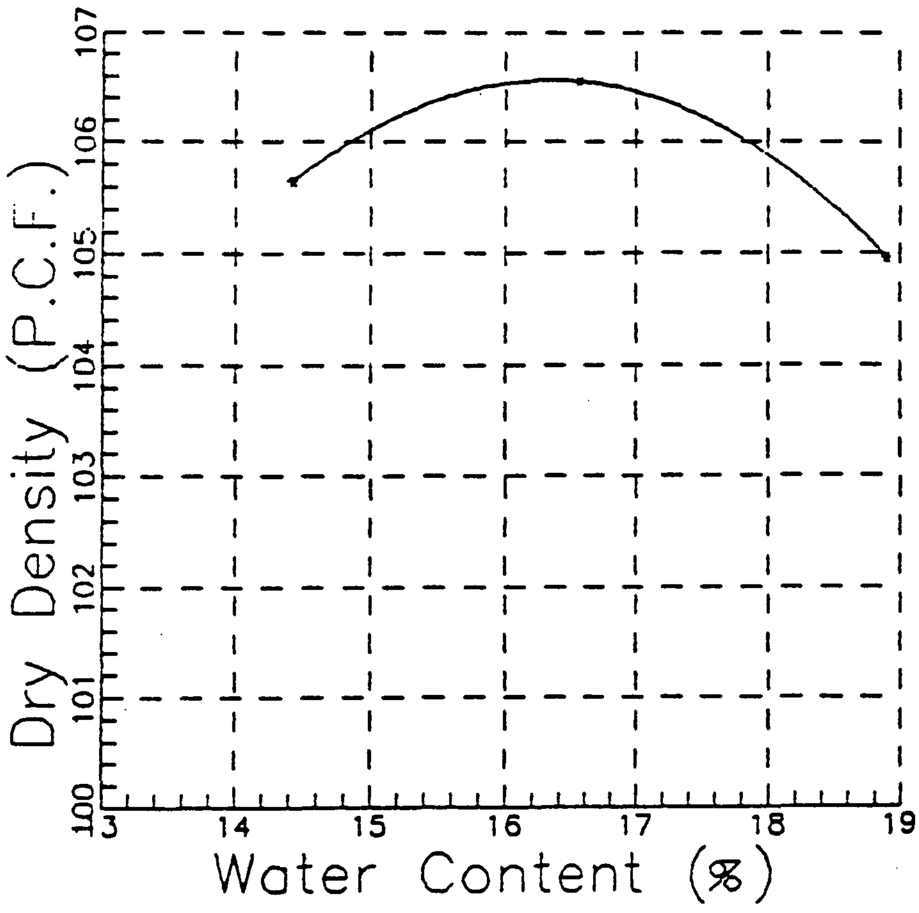
Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Cd
114	Retest # 112	Finish Windblown Grade	Brown Silty Sand	2.5	103.3	11.3	110.6	93
115	Retest # 110	"	"	4.5	102.6	11.3	110.6	93
116	Retest # 114	"	"	5.8	106.0	11.3	110.6	96
117	Retest # 115	"	"	3.1	108.1	11.3	110.6	98
118	Sand Cone correlation # 117	"	"	2.9	107.9	11.3	110.6	98

J-80

Moisture-Density Analysis
ASTM D-698

Project: Tailings Reclamation
Split Rock Millsite
Client: Western Nuclear, Inc.

Job No.: 4779.1 RM
Date: 8-7-90
Max. Dry Dens.: 106.56
Opt. Moisture : 16.35



Sample From:
Interim Cover
Sample No. 7

Sampled by: RWA
Tech: RWA

Sample Description:
Brown Silty Sand

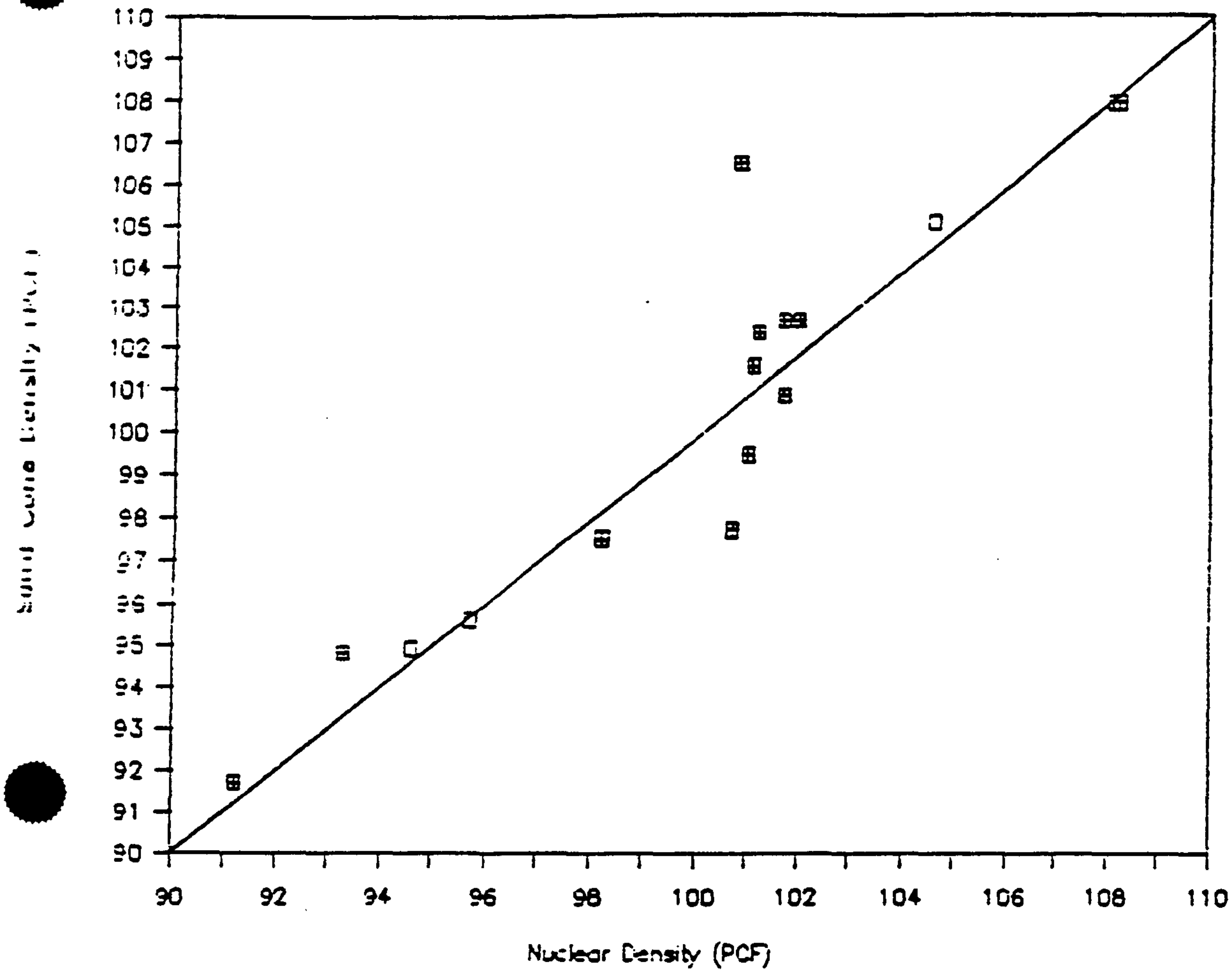
% passing #200: 4.23%
Plasticity Index: Non Plastic

INBERG-MILLER ENGINEERS

J-81

Nuclear Density/Sand Cone

Correlation



~~K82~~

1-9-92

J-82

Nuclear Moisture-Density Gauge/
Sand Cone Density Correlation

Correlation No.	Test Numbers	Nuclear Density (PCF)	Sand Cone Density (PCF)
1	9 & 10	100.8	106.5
2	19 & 20	101.0	99.5
3	21 & 22	101.7	100.9
4	24 & 25	93.3	94.8
5	38 & 39	101.1	101.6
6	45 & 46	101.2	102.4
7	49 & 50	91.2	91.7
8	53 & 54	100.7	97.7
9	57 & 58	108.2	107.9
10	61 & 62	98.2	97.5
11	68 & 69	102.0	102.7
12	72 & 73	101.7	102.7
13	88 & 89	104.6	105.1
14	91 & 92	95.7	95.6
15	94 & 95	94.6	94.9
16	117 & 118	108.1	107.9

~~X-83~~
J-83

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: August 17, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 8-14 Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% C
119	7850N 9850E Area 1	Final Interim Cover Grade	Brown Silty Sand	3.0	101.6	16.4	106.4	
120	7850N 9700E Area 1	"	"	4.0	102.0	16.4	106.4	9
121	Sand Cone correlation # 120	"	"	3.5	102.8	16.4	106.4	9
122	7850N 9600E Area 1	"	"	5.7	104.2	16.4	106.4	9
123	7850N 9500E Area 1	"	"	2.5	103.3	16.4	106.4	9
124	7950N 9560E Area 1	"	"	2.9	101.9	16.4	106.4	9
123	7950N 9600E Area 1	"	"	2.1	102.3	16.4	106.4	9

~~#8~~
1-9-a - J-84

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 17, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 8-14/8-15   Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
126	7950N 9700E Area 1	Final Interim Cover Grade	Brown Silty Sand	1.8	100.7	16.4	106.4	95
127	7950N 9850E Area 1	"	"	3.1	101.9	16.4	106.4	96
128	7750N 9800E Area 1	"	"	7.1	101.3	16.4	106.4	95
129	7750N 9700E Area 1	"	"	2.2	101.8	16.4	106.4	96
130	7750N 9700E Area 1	"	"	3.8	101.8	16.4	106.4	90
131	7750 9500E Area 1	"	"	2.9	96.2	16.4	106.4	90
132	Retest # 130	"	"	3.8	101.5	16.4	106.4	95
133	Retest # 131	"	"	4.0	99.8	16.4	106.4	94

~~K-85~~
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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 17, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 8-15/8-16   Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% C
134	7550N 9800E Area 1	Final Interim Cover Grade	Brown Silty Sand	2.8	104.9	16.4	106.4	
135	7550N 9700E Area 1	"	"	3.1	104.6	16.4	106.4	98
136	7550N 9600E Area 1	"	"	2.6	103.2	16.4	106.4	97
137	7550N 9500E Area 1	"	"	4.8	103.7	16.4	106.4	97
138	6500N 9200E	Final Tailings Grade	Gray Silty Sand	4.1	105.4	12.4	105.8	100
139	6500N 8935E	"	"	5.9	107.5	12.4	105.8	102
140	Retest # 133 Area 1	Final Interim Cover Grade	Brown Silty Sand	3.1	105.6	16.4	106.4	99

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 17, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 8-16 Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
141	7450N 9460E Area 1	Final Interim Cover Grade	Brown Silty Sand	6.7	102.6	16.4	106.4	96
142	7450N 9600E Area 1	"	"	6.2	104.1	16.4	106.4	98
143	Sand Cone correlation # 142	"	"	5.7	104.7	16.4	106.4	98
144	7450N 9700E Area 1	"	"	5.9	104.5	16.4	106.4	98
145	7450N 9800E Area 1	"	"	5.0	103.1	16.4	106.4	97
146	Sand Cone correlation # 145	"	"	5.1	102.9	16.4	106.4	97

~~K57~~
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REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: August 24, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 8-20 Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
147	7350N 9350E Area 1	Finish Interim Cover Grade	Brown Silty Sand	3.5	103.7	16.4	106.4	(
148	Sand Cone correlation # 147	"	"	3.2	104.1	16.4	106.4	98
149	7350N 9450E Area 1	"	"	3.3	104.4	16.4	106.4	98
150	7350N 9550E Area 1	"	"	3.0	106.7	16.4	106.4	100
151	7350N 9650E Area 1	"	"	3.5	102.3	16.4	106.4	96
152	7250N 9650E Area 1	"	"	3.1	104.6	16.4	106.4	98
153	7250N 9550E Area 1	"	"	1.7	108.1	16.4	106.4	1

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Page _1_ of _6

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: August 24, 1990

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 8-20   Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
147	7350N 9350E Area 1	Finish Interim Cover Grade	Brown Silty Sand	3.5	103.7	16.4	106.4	[illegible]
148	Sand Cone corr-elation # 147	"	"	3.2	104.1	16.4	106.4	98
149	7350N 9450E Area 1	"	"	3.3	104.4	16.4	106.4	98
150	7350N 9550E Area 1	"	"	3.0	106.7	16.4	106.4	100
151	7350N 9650E Area 1	"	"	3.5	102.3	16.4	106.4	96
152	7250N 9650E Area 1	"	"	3.1	104.6	16.4	106.4	98
153	7250N 9550E Area 1	"	"	1.7	108.1	16.4	106.4	[illegible]

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 24, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 8-20/8-21   Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
154	7250N 9450E Area 1	Finish Interim Cover Grade	Brown Silty Sand	3.0	103.8	16.4	106.4	98
155	Sand Cone correlation # 154	"	"	3.5	103.3	16.4	106.4	97
156	7250N 9350E Area 1	"	"	2.7	104.1	16.4	106.4	98
157	6950N 9750E Area 1	"	"	4.2	109.7	16.4	106.4	103
158	6950N 9650E Area 1	"	"	6.7	104.0	16.4	106.4	98
159	Sand Cone correlation # 158	"	"	6.1	104.0	16.4	106.4	98

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 24, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 8-21   Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% C
160	6950N 9450E Area 1	Finish Interim Cover Grade	Brown Silty Sand	2.5	107.3	16.4	106.4	
161	Sand Cone corr-elation # 160	"	"	2.5	107.7	16.4	106.4	101
162	6950N 9350E Area 1	"	"	5.6	110.8	16.4	106.4	104
163	7050N 9350E Area 1	"	"	2.7	108.0	16.4	106.4	102
164	Sand Cone corr-elation # 163	"	"	3.0	108.3	16.4	106.4	102
165	7050N 9450E Area 1	"	"	3.0	105.3	16.4	106.4	

~~K-90~~
J-90

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 24, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 8-21   Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
☒ Sand Cone Method (ASTM D1556)
☒ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
☒ Standard Proctor (ASTM D698)
☐ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Com
166	7050N 9650E Area 1	Finish Interim Cover Grade	Brown Silty Sand	4.4	105.2	16.4	106.4	99
167	7050N 9750E Area 1	"	"	1.9	108.4	16.4	106.4	102
168	Sand Cone corr-elation # 167	"	"	1.7	108.1	16.4	106.4	103
169	7200N 9750E Area 1	"	"	1.7	107.1	16.4	106.4	100
170	7150N 9650E Area 1	"	"	3.9	106.2	16.4	106.4	100
171	Sand Cone corr-elation # 170	"	"	4.2	105.9	16.4	106.4	100

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 24, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 8-21/8-23 Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Co
172	7150N 9450E Area 1	Finish Interim Cover Grade	Brown Silty Sand	2.0	105.4	16.4	106.4	
173	7150N 9350E Area 1	"	"	3.0	103.3	16.4	106.4	97
174	Sand Cone corr- elation # 173	"	"	3.3	103.0	16.4	106.4	97
175	6750N 9700E Area 1	"	"	2.9	105.8	16.4	106.4	99
176	6750N 9600E Area 1	"	"	3.5	106.1	16.4	106.4	100
177	Sand Cone corr- elation # 176	"	"	3.4	106.6	16.4	106.4	100

J-92

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: August 24, 1990

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 8-23 Tests by: RWA

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
178	6750N 9500E Area 1	Finish Interim Cover Grade	Brown Silty Sand	4.4	106.9	16.4	106.4	100
179	6750N 9400E Area 1	"	"	2.8	105.9	16.4	106.4	100
180	Sand Cone correlation # 179	"	"	3.3	105.4	16.4	106.4	99
181	6650N 9400E Area 1	"	"	1.7	109.6	16.4	106.4	103
182	6650N 9500E Area 1	"	"	4.0	103.7	16.4	106.4	97
183	6650N 9600E Area 1	"	"	2.7	109.0	16.4	106.4	102
184	6650N 9700E Area 1	"	"	4.6	105.4	16.4	106.4	99

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Western Nuclear, Inc.
lit Rock Millsite - Tailings Reclamation
79.1-RM

Nuclear Moisture-Density Gauge/
Sand Cone Density Correlation

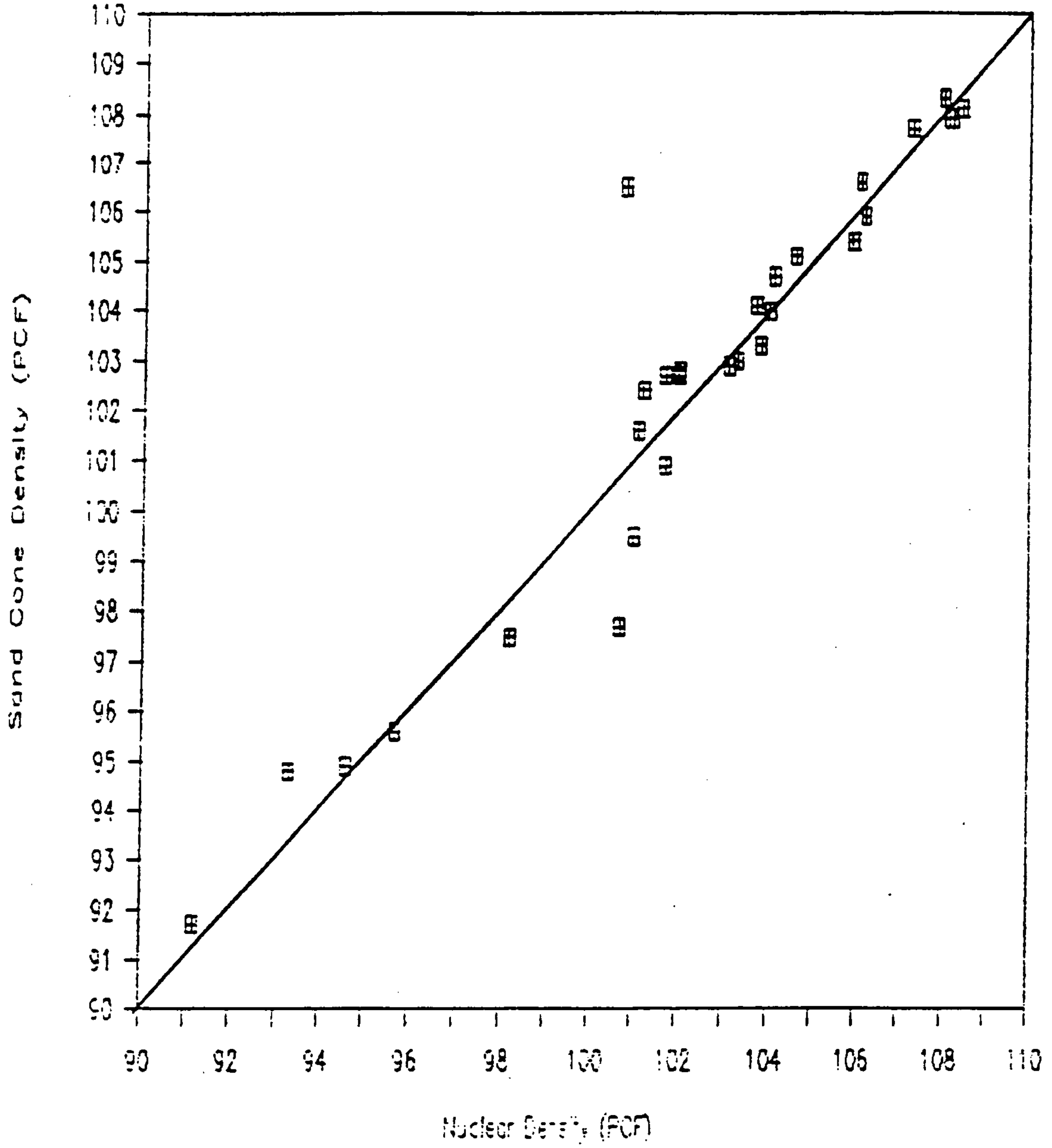
Correlation No.	Test Numbers	Nuclear Density (PCF)	Sand Cone Density (PCF)
1	9 & 10	100.8	106.5
2	19 & 20	101.0	99.5
3	21 & 22	101.7	100.9
4	24 & 25	93.3	94.8
5	38 & 39	101.1	101.6
6	45 & 46	101.2	102.4
7	49 & 50	91.2	91.7
8	53 & 54	100.7	97.7
9	57 & 58	108.2	107.9
10	61 & 62	98.2	97.5
11	68 & 69	102.0	102.7
12	72 & 73	101.7	102.7
13	88 & 89	104.6	105.1
14	91 & 92	95.7	95.6
15	94 & 95	94.6	94.9
16	117 & 118	108.1	107.9
17	120 & 121	102.0	102.8
18	142 & 143	104.1	104.7
19	145 & 146	103.1	102.9
20	147 & 148	103.7	104.1
21	154 & 155	103.8	103.3
22	158 & 159	104.0	104.0
23	160 & 161	107.3	107.7
24	163 & 164	108.0	108.3
25	167 & 168	108.4	108.1
26	170 & 171	106.2	105.9
27	173 & 174	103.3	103.0
28	176 & 177	106.1	106.6
29	179 & 180	105.9	105.4

Through 8-24-90

~~K-9-~~
1-9-9 J-94

Nuclear Density/Sand Cone

Correlation



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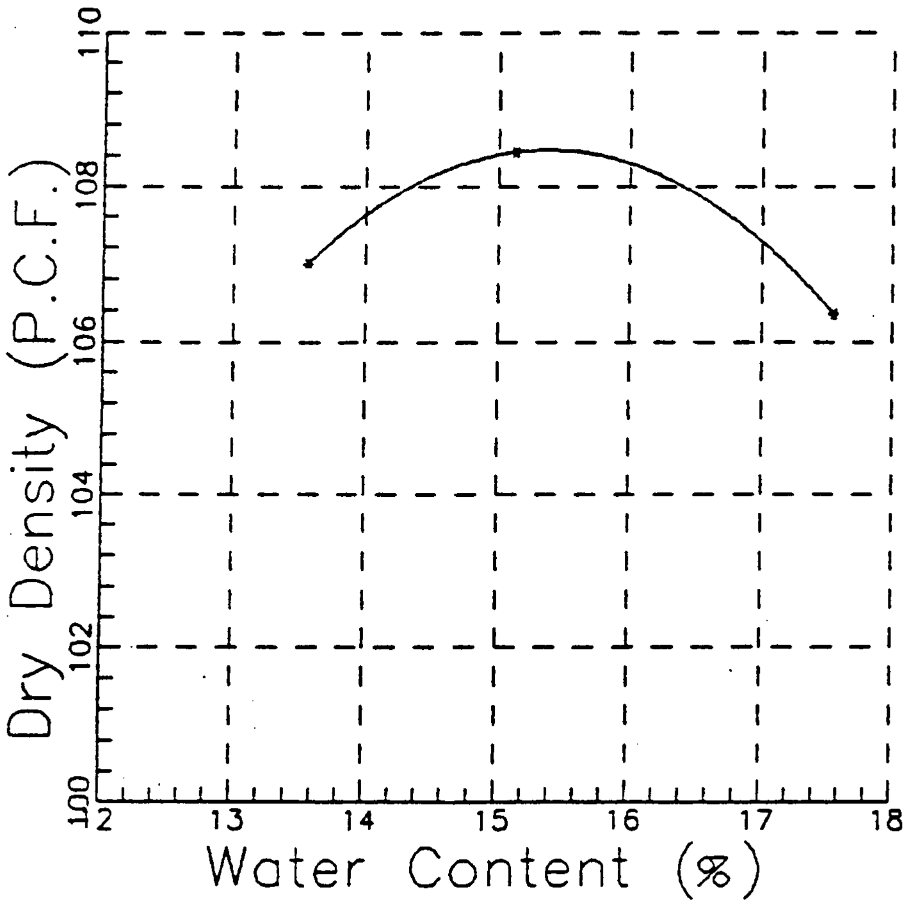
Moisture-Density Analysis
ASTM D-698

Project: Tailings Reclamation
Split Rock Millsite
Client: Western Nuclear, Inc.

Job No.: 4779.1 RM
Date: 8-20-90
Max. Dry Dens.: 108.4
Opt. Moisture : 15.4



Sample From:
Northwest Borrow
Sample No. 8

Sampled by: WAU
Tech: WAU

Sample Description:
Brown Silty Sand

% passing #200: 5.53%
Plasticity Index: Non Plastic

INBERG-MILLER ENGINEERS

J-96

REPORT OF FIELD COMPACTION TEST RESULTS

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15, 1

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 9-12   Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
185	6700N 9070E Area 1	Finish Interim Cover Grade	Brown Silty Sand	1.8	106.5	11.3	110.6	96
186	Sand Cone corr-elation # 185	"	"	2.1	106.9	11.3	110.6	97
187	6600N 9150E Area 1	"	"	1.5	106.1	11.3	110.6	96
188	6400N 9250E Area 1	"	"	1.9	110.2	11.3	110.6	100
189	6400N 9500E Area 1	"	"	1.0	107.6	11.3	110.6	97
190	5500N 7680E Area 2	"	"	0.7	107.3	11.3	110.6	97
191	8500N 10200E Area 3	"	"	1.3	110.6	11.3	110.6	100

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Page _2_ of _1_

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15, 1

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 9-14   Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Com
192	8400N 10000E Area 3	Finish Interim Cover Grade	Brown Silty Sand	0.9	108.0	11.3	110.6	
193	Sand Cone correlation # 192	"	"	1.3	107.9	11.3	110.6	9
194	8300N 9985E Area 3	"	"	0.7	104.8	11.3	110.6	95
195	8200N 9600E Area 3	"	"	0.9	107.0	11.3	110.6	97
196	8500N 9700E Area 3	"	"	1.3	99.8	11.3	110.6	90
197	Sand Cone correlation # 196	"	"	1.1	100.1	11.3	106.4	91

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15, 1

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 9-14   Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Com
198	8600N 9915E Area 3	Finish Interim Cover Grade	Brown Silty Sand	1.0	103.0	11.3	110.6	93
199	Sand Cone correlation # 198	"	"	1.0	102.7	11.3	110.6	93
200	8700N 9580E Area 3	"	"	1.3	97.3	11.3	110.6	88
201	Sand Cone correlation # 200	"	"	1.6	96.5	11.3	110.6	87
202	8600N 9500E Area 3	"	"	1.3	99.3	11.3	110.6	90
203	8600N 9550E Area 3	"	"	1.0	104.0	11.3	110.6	94

Page _4_ of _1_

REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15, 19

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 9-14 Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
204	8560N 9800E Area 3	Finish Interim Cover Grade	Brown Silty Sand	0.9	108.5	11.3	110.6	(3
205	8500N 9500E Area 3	"	"	1.4	106.0	11.3	110.6	96
206	Sand Cone correlation # 205	"	"	1.7	105.7	11.3	110.6	96
207	8400N 9310E Area 3	"	"	0.2	100.3	11.3	110.6	91
208	8400N 9040E Area 3	"	"	2.2	100.8	11.3	110.6	91
209	Sand Cone correlation # 208	"	"	2.5	100.9	11.3	110.6	91

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15, 19

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 9-14   Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
210	8300N 9300E Area 3	Finish Interim Cover Grade	Brown Silty Sand	1.4	105.5	11.3	110.6	95
211	8400N 8800E Area 3	"	"	1.6	108.8	11.3	110.6	98
212	Sand Cone correlation # 211	"	"	2.0	108.5	11.3	110.6	98
213	8300N 8700E Area 3	"	"	1.3	96.3	11.3	110.6	87
214	Retest # 213	"	"	1.5	100.0	11.3	110.6	90
215	Sand Cone correlation # 214	"	"	1.3	100.1	11.3	110.6	91

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15, 19

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 9-14 Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION
_x_ Sand Cone Method (ASTM D1556)
_x_ Nuclear Method (ASTM D2922)

MOISTURE-DENSITY RELATIONSHIP
_x_ Standard Proctor (ASTM D698)
___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
216	8300N 8600E Area 3	Finish Interim Cover Grade	Brown Silty Sand	2.2	101.8	11.3	110.6	[illegible]
217	8400N 8400E Area 3	"	"	1.5	101.5	11.3	110.6	92
218	Sand Cone correlation # 217	"	"	2.1	101.0	11.3	110.6	91
219	8400N 8200E Area 3	"	"	1.0	104.5	11.3	110.6	95
220	8500N 8200E Area 3	"	"	1.4	106.5	11.3	110.6	96
221	8400N 8100E Area 3	"	"	1.2	104.8	11.3	110.6	95
222	8400N 7800E Area 3	"	"	1.0	96.5	11.3	110.6	[illegible]

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REPORT_OF_FIELD_COMPACTION_TEST_RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15, 1

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 9-14 Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST_RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Com
223	Retest # 222	Finish Interim Cover Grade	Brown Silty Sand	1.4	105.5	11.3	110.6	95
224	8600N 8000E Area 3	"	"	1.0	104.0	11.3	110.6	94
225	8600N 8400E Area 3	"	"	0.7	104.3	11.3	110.6	94
226	8600N 8600E Area 3	"	"	1.7	104.8	11.3	110.6	95
227	Sand Cone correlation # 226	"	"	2.0	104.8	11.3	110.6	95
228	8650N 8800E Area 3	"	"	2.1	105.3	11.3	110.6	95
229	8700N 8700E Area 3	"	"	1.1	108.8	11.3	110.6	98

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REPORT_OF_FIELD_COMPACTION_TEST_RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15, 1

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM Test Date: 9-14 Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST_RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Com
230	8800N 8800E Area 3	Finish Interim Cover Grade	Brown Silty Sand	1.1	108.8	11.3	110.6	[illegible]
231	8600N 8800E Area 3	"	"	1.4	105.5	11.3	110.6	95
232	Sand Cone correlation # 231	"	"	1.1	105.9	11.3	110.6	96
233	8800N 9000E Area 3	"	"	1.5	113.8	11.3	110.6	10
234	8600N 9200E Area 3	"	"	0.9	111.0	11.3	110.6	100
235	8700N 9200E Area 3	"	"	1.2	105.3	11.3	110.6	95
236	8500N 9300E Area 3	"	"	1.3	98.8	11.3	110.6	[illegible]

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite Tailings Reclamation

Date: September 15, 1

To:
Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 9-14   Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
_x_ Sand Cone Method (ASTM D1556)	_x_ Standard Proctor (ASTM D698)
_x_ Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Com
237	8500N 9250E Area 3	Finish Interim Cover Grade	Brown Silty Sand	1.2	100.3	11.3	110.6	91
238	Sand Cone correlation # 237	"	"	1.0	100.5	11.3	110.6	91
239	8600N 8750E Area 3	"	"	1.4	103.5	11.3	110.6	94
240	8550N 8750E Area 3	"	"	1.7	104.3	11.3	110.6	94
241	7300N 9100E Area 3	"	"	1.5	106.5	11.3	110.6	96
242	Sand Cone correlation # 241	"	"	1.7	106.2	11.3	110.6	96

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REPORT OF FIELD COMPACTION TEST RESULTS, continued

Project: Split Rock Millsite
Tailings Reclamation

Date: September 15, 19

To: Western Nuclear, Inc.
ATTENTION: ROLAND COLLINS
P.O. Box 630
Jeffrey City, Wyoming 82310

Job No.: 4779.1-RM   Test Date: 9-14   Tests by: WAU

TEST METHODS:

FIELD DENSITY DETERMINATION	MOISTURE-DENSITY RELATIONSHIP
x Sand Cone Method (ASTM D1556)	x Standard Proctor (ASTM D698)
x Nuclear Method (ASTM D2922)	___ Modified Proctor (ASTM D1557)

TEST RESULT

Test No.	Loc.	Test Elev.	Mat. Desc.	Moist. %	Dry Dens. pcf	Opt. Moist. Cont. %	Max. Dry Dens. pcf	% Comp
243	7300N 9100E Area 2	Finish Interim Cover Grade	Brown Silty Sand	1.5	106.5	11.3	110.6	[illegible]
244	7200N 8900E Area 2	"	"	1.5	103.0	11.3	110.6	93
245	7000N 9000E Area 2	"	"	1.8	101.3	11.3	110.6	91
246	Sand Cone correlation # 245	"	"	2.1	101.5	11.3	110.6	92
247	7000N 8800E Area 2	"	"	1.3	103.8	11.3	110.6	94
248	6600N 8400E Area 2	"	"	1.5	99.0	11.3	110.6	90
249	6900N 8900E Area 2	"	"	1.3	104.3	11.3	110.6	[illegible]

~~B-100~~
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Western Nuclear, Inc.
Split Rock Millsite - Tailings Reclamation
4779.1-RM

TABLE E-1
SUMMARY

Nuclear Moisture-Density Gauge/
Sand Cone Density Correlation

Correlation No.	Test Numbers	Nuclear Density (PCF)	Sand Cone Density (PCF)
1	9 & 10	100.8	106.5
2	19 & 20	101.0	99.5
3	21 & 22	101.7	100.9
4	24 & 25	93.3	94.8
5	38 & 39	101.1	101.6
6	45 & 46	101.2	102.4
7	49 & 50	91.2	91.7
8	53 & 54	100.7	97.7
9	57 & 58	108.2	107.9
10	61 & 62	98.2	97.5
11	68 & 69	102.0	102.7
12	72 & 73	101.7	102.7
13	88 & 89	104.6	105.1
14	91 & 92	95.7	95.6
15	94 & 95	94.6	94.9
16	117 & 118	108.1	107.9
17	120 & 121	102.0	102.8
18	142 & 143	104.1	104.7
19	145 & 146	103.1	102.9
20	147 & 148	103.7	104.1
21	154 & 155	103.8	103.3
22	158 & 159	104.0	104.0
23	160 & 161	107.3	107.7
24	163 & 164	108.0	108.3
25	167 & 168	108.4	108.1
26	170 & 171	106.2	105.9
27	173 & 174	103.3	103.0
28	176 & 177	106.1	106.6
29	179 & 180	105.9	105.4
30	185 & 186	106.5	106.9
31	192 & 193	108.0	107.9
32	196 & 197	99.8	100.1
33	198 & 199	103.0	102.7
34	200 & 201	97.3	96.5
35	205 & 206	106.0	105.7
36	208 & 209	100.8	100.9
37	211 & 212	108.8	108.5
38	214 & 215	100.0	100.1
39	217 & 219	101.5	101.0

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tern Nuclear, Inc.
it Rock Millsite - Tailings Reclamation
9.1-RM

TABLE B-1 (CON'D)

SUMMARY

Nuclear Moisture-Density Gauge/
Sand Cone Density Correlation

Correlation No.	Test Numbers	Nuclear Density (PCF)	Sand Cone Density (PCF)
40	226 & 227	104.8	104.8
41	231 & 232 ✓	105.5	105.9
42	237 & 238 ✓	100.3	100.5
43	241 & 242 ✓	106.5	106.2
44	245 & 246 ✓	101.3	101.5
45	250 & 251 ✓	103.5	103.9
46	255 & 256 ✓	110.5	110.0
47	258 & 259 ✓	105.5	105.8
48	261 & 262 ✓	101.3	101.0
49	264 & 265 ✓	112.0	111.5
50	270 & 271 ✓	107.3	107.6
51	274 & 275	100.3	102.3
52	281 & 282	105.8	104.9

Through 9-19-90

~~R 103~~

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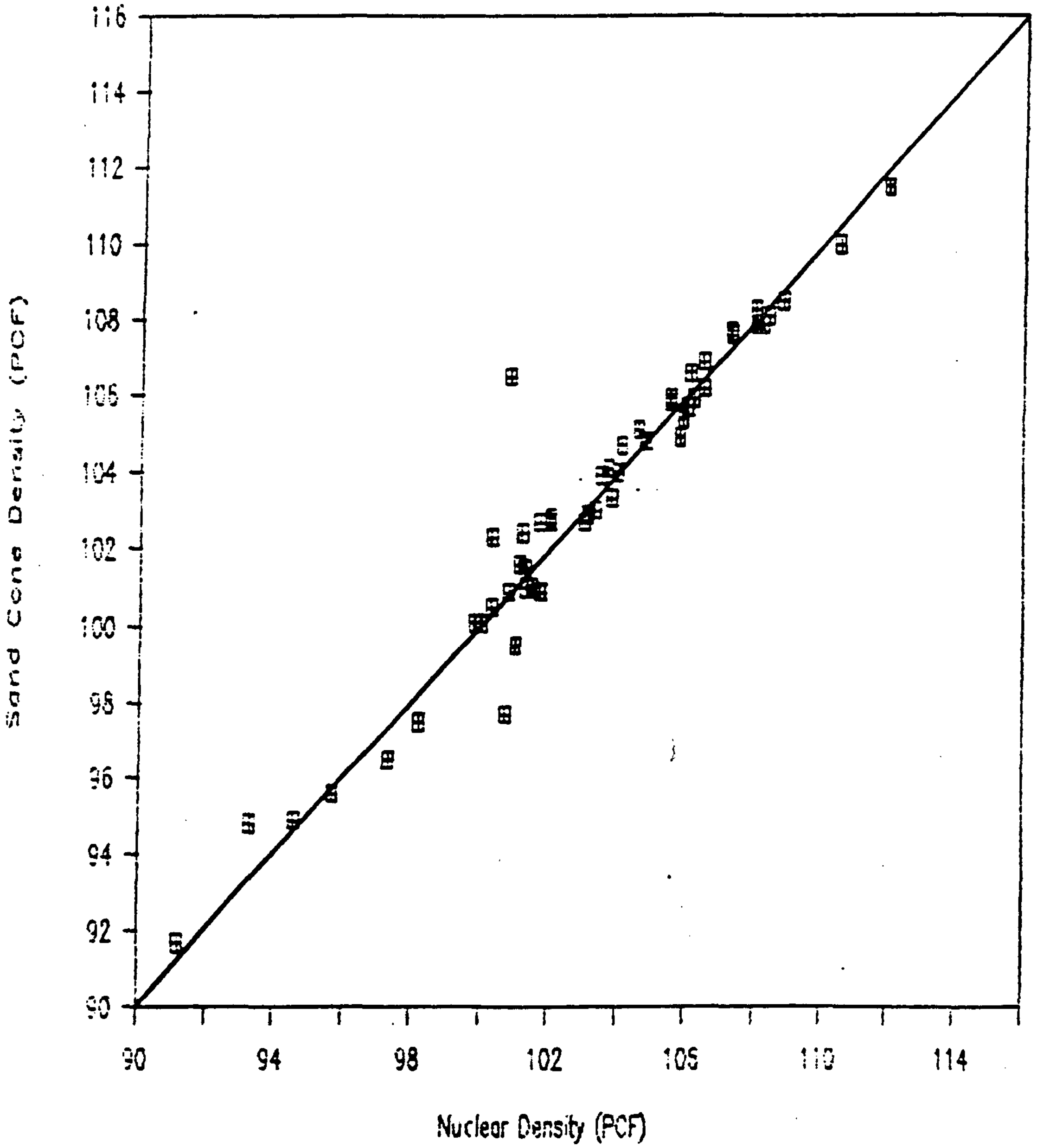
FIGURE B-1

Nuclear Density/Sand Cone

Correlation



APPENDIX K

HEALTH AND SAFETY PROGRAM RESPONSES

~~41~~ K-1

9.1 General

1st paragraph, last sentence. Strike "site-specific".
2nd paragraph. Strike "OHSA".
4th paragraph. Add "Safety Director".

9.2.2 1st paragraph. Stike "weekly", insert "monthly"

The following proposed revisions reflect current WNI operating procedures and are consistant with NRC Regulatory Guide 8.31 "Information Relevant To Ensuring That Occupational Radiation Exposures At Uranium Mills Will Be As Low As Is Reasonably Achievable (ALARA)".

Move 9.3.2 Management Audit to 9.4.3 Management Audit .

Move 9.3.3 ALARA Program and 9.3.4 Radiation Safety Administration Procedures to 9.4.1

Relabel 9.4 Hazard Analysis as 9.3 Hazard Analysis .

Relabel 9.5 Radiological Safety as 9.4 Radiological Safety .

Revise this section as follows.

9.4.1 ALARA Program

The Owner, RSO and all workers will share in the responsibility of a written and practiced ALARA philosophy. The RSO developes and administers the ALARA program in accordance with NRC Regulatory Guide 8.31 "Information Relevant To Ensuring That Occupational Radiation Exposures At Uranium Mills Will Be As Low As Reasonably Achievable, (ALARA)" and is active in the review and approval of plans for changes in operating procedures. This ensures that the plans do not adversely affect the protection program against uranium and its decay products. The program consists of specific worker training regarding the potential radiological hazards of each task, applicable routine radiation surveys as required by 10 CFR Part 20. Respiratory protection, a bioasssay program, independent inspections by RSO or his designate, ongoing review of both personnel and onsite monitoring data, and modification of work practices as appropriate are also part of the ALARA program. At least annually, an audit will be performed of the radiation protection and ALARA program.

K-2

9.4.2 Training

Insert 9.9.1 Training from F-80 in here. Add Sub in front of contractors in the last paragraph.

Add "The site RSO has completed four weeks of specialized classroom training in health physics specifically applicable to uranium milling. In addition, the RSO has attended refresher training on uranium mill health physics.

9.4.3 Management Audits

Insert 9.3.2 Management Audits from F-72 in here

9.4.4 Radiation Work Permits

Radiation Work Permits (RWP) are required for all activities involving work around radioactive materials and are issued in accordance with Section A of the WNI Written Procedures.

9.4.5 Radiation Surveys

Radiation surveys will be performed as described in NRC Regulatory Guide 8.30 "Health Physics Surveys in Uranium Mills".

Gamma

External gamma surveys of the project area will be performed monthly with a gamma detector (PRM-7 or equivalent). Time studies of the workers will be performed and documented. The time any worker is on the site will be documented on the Contractor Daily Log and/or the contractors' time sheets. The time and gamma exposure rate will be transfered to the Contractors Restricted Area Occupancy Log for subsequent calculation for gamma exposure. The gamma exposure will be recorded.

Airborne Radionuclides

Surveys for airborne radionuclides will be performed weekly during the construction activities. At least one worker in each construction area will be required to wear a calibrated constant flow air sampling pump equipped with a 25 mm filter in a filter holder. The sampling apparatus will be distributed at the beginning of the shift and collected at the end of the shift. The filters will be analyzed on a Ludlum 2000 scaler equipped with an appropriate alpha scintillator or equivalent. If the calculated uranium concentration exceeds 10 percent of Maximum Permissable Concentration (MPC), exposure calculations will be performed and recorded for each worker in that construction area.

9.4.6 Radiological Contamination Surveys

Insert 9.6.1.2 Radiological Contamination Survey Program in here.

1st paragraph, 1st sentence. Insert "construction equipment cabs" before lunch rooms.

9.4.7 Respiratory Protection

Respiratory protection will be provided to workers in accordance with the provisions of 10 CFR Part 20.103 (c)(d)(e) and described in NRC Regulatory Guide 8.15 "Applicable Programs For Respiratory Protection". Respirators will be required whenever the weekly samples for airborne radionuclides exceed 50 percent of MPC.

A routine physical evaluation (pulmonary function test) will be required for all worker who will use respirators.

As part of the respiratory protection program, bioassays will be collected and analyzed in accordance with NRC Regulatory Guide 8.22 "Bioassays at Uranium Mills". Specifically, urine samples will be collected from each worker on the first work day. Urine samples may be collected during the course of the work if airborne radionuclide concentration exceed 50 percent of MPC to evaluate the effectiveness of the respiratory protection program. A final urine sample will be collected from each worker on their last work day.

9.4.8 Inspections

Daily inspections are conducted by the RSO or his designate and recorded on the Contractors Daily Log. All monitoring and exposure data will be reviewed quarterly and any trends or deviations in the ALARA phlosophy will be addressed and a formal report will be submitted to the General Manager.

9.4.9 Restricted Area Access

In accordance with Condition 37 of Source Material License SUA-56, all entrances to the restricted area are conspicuously posted in accordance with Section 20.203(e)(2) of 10 CFR Part 20 and with the words, "Any area within this facility may contain radioactive material". In addition, a sign with the words "Restricted Area, No Admittance" is conspicuously posted at each entrance.

9.4.10 Minumizing Dusting

Dusting from the tails will be minimized with a water truck spraying water over haul roads and active working areas.

9.4.11 Written Procedures

Written procedures are established for site reclamation activities which include sample collection, instrument operation, instrument calibration and documentation.

All instruments will be calibrated semi-annually or after any repair.

The results of sampling, analysis, surveys, and monitoring, the calibration of equipment, reports on audits and inspections, and all meetings and training courses will be documented and maintained

9.4.12 Contractor Responsibilities

The contractor will provide all industrial safety equipmint for his employees unless otherwise stated in the contract. All contractor personnel, site visitors and regulatory personnel shall provide their own equipment which meets or exceeds the levels specified in the HASP.

The contractor shall provide the routine physical evaluation (pulmonary function test) for employees required to wear respirators

Delete 9.6 Exposure Monitoring

Delete 9.6.1 Radiation Exposures

Delete 9.6.1.1 Airborne Radiation Surveys

Move 9.6.1.2 Radiological contamination Survey Program to 9.4.5

9.7 1st paragraph. At end add "The contractor shall provide a copy of their "Emergency Procedures".

Move to 9.4.2