6-month update for SN 514E

INITIAL ENTRIES

SCIENTIFIC NOTEBOOK 514E TITLE:

Thermal Effects on Flow Key Technical Issue

TITLE OF TASK 1:

Compilation of pre-existing pneumatic, hydraulic, and thermal property data from the unsaturated zone of Yucca Mountain, Nevada, and the Apache Leap Research Site, Arizona.

TASK 1 STAFF:

Cynthia L. Dinwiddie
Randall W. Fedors
Walter A. Illman

DESCRIPTION OF TASK 1 OBJECTIVES AND THE APPROACH TAKEN TO ACHIEVE THE STATED OBJECTIVES:

The draft report "Geostatistical analysis of pneumatic, hydraulic, and thermal properties of unsaturated fractured rocks at the Apache Leap Research Site, a Yucca Mountain analog" is being prepared, and one of its objectives is to assess the quality of the Apache Leap Research Site as an analog for the unsaturated zone at Yucca Mountain. In order to meet this objective, CNWRA staff intend to summarize the collection of, provide test descriptions for, and ultimately compile pre-existing pneumatic, hydraulic, and thermal property data from DOE literature, such that it may be compared with similar data collected from the Apache Leap Research Site. Data will be compiled into two tables for presentation in the third chapter of the aforementioned report. The first table is to be a comparison of Apache Leap Research Site and Yucca Mountain field-estimated air permeabilities and their apparent relationship to fracture density and degree of welding. The second table is to be a comparison of all pneumatic, hydraulic, and thermal properties that were estimated at both the Apache Leap Research Site and within the repository horizon of Yucca Mountain. Data from the Apache Leap Research Site are to be compiled from the available literature–both peer-reviewed journal articles as well as various NUREGs originating from the US NRC Office of Nuclear Regulatory Research.

SPECIAL PERSONNEL TRAINING OR QUALIFICATION REQUIREMENTS:

Member of the CNWRA technical staff.

IN-PROCESS ENTRIES

03/29/02

Microsoft Excel 97 SR-2, installed on the CNWRA desk-top computer known as ATLANTIS, was utilized in the development of the two aforementioned tables. Documentation for the origination of pre-existing pneumatic, hydraulic, and thermal property data (data which was

either provided by DOE or through the Apache Leap Research Site literature) was accomplished by making explicit reference to the origin of the data in a comment associated with each spreadsheet cell. Table 3-1 and Table 3-2 are reproduced on the following pages, dated March 29, 2002, and the original Microsoft Excel electronic files with documentation comments are located on ATLANTIS: D:\cnwra\TEF\Scientific Notebook\Geostatistics Report Table 3-1.xls and
D:\cnwra\TEF\Scientific Notebook\Geostatistics Report Table 3-2.xls

Additionally, the references through which all original data were provided are supplied at the end of this scientific notebook, as well as references that support conclusions made by the authors in the third chapter of the draft report "Geostatistical analysis of pneumatic, hydraulic, and thermal properties of unsaturated fractured rocks at the Apache Leap Research Site, a Yucca Mountain analog". The only items pertaining to the third chapter of the aforementioned report that not completely covered in this scientific notebook are data from the Apache Leap Research Site and fracture density/frequency data, which will be found in SN No. 510 and SN No. 432, respectively.

Table 3-1. Comparison of Apache Leap Research Site and Yucca Mountain field-estimated air permeabilities and their relationship to fracture density and degree of welding.

		Fracture Permeability, k_a	Fracturing/ Fracture Density	Degree of Welding
Apache Leap Research Site X-, Y-, and Z-series boreholes		7.94×10^{-16} m^2 [8.05×10^{-4} D]	0.98-3.6 m^{-1} [0.30-1.1 ft^{-1}]	slightly welded
Yucca Mountain (PTn)	NRG-6, NRG-7a	?	3.1-2.7 m^{-1} [0.9-0.8 ft^{-1}]	nonwelded to partially welded
	ESF Alcove 4	1.00×10^{-13} m^2 [0.10 D]	discretely faulted and fractured	
	Uncalibrated: UPCA, NRG-7a	$0.16\text{-}3.20\times10^{-12}$ m^2 [0.16-3.24 D]		
	Calibrated Base Case	$0.26\text{-}20\times10^{-12}$ m^2 [0.26-20 D]		
Yucca Mountain Tptpmn (tsw34) ESF Data	Alcove 6	1.26×10^{-12} m^2 [1.28 D]	highly fractured	moderately to densely welded
	Niche 35+66	1.00×10^{-13} m^2 [0.10 D]	brecciated; > Niche 36+50	
	Niche 36+50	3.98×10^{-14} m^2 [4.03×10^{-2} D]	moderately fractured; < Niche 35+66	
	Niche 31+07	3.98×10^{-14} m^2 [4.03×10^{-2} D]	moderately fractured	
	Niche 47+88	1.00×10^{-13} m^2 [0.10 D]	intensely fractured	
Yucca Mountain Tptpmn (tsw34) Deep Borehole Data	UZ-14, SD-7, SD-9, SD-12, NRG-6, NRG-7a	?	6.4-11.2 m^{-1} [2.0-3.4 ft^{-1}]	
	Uncalibrated: SHT, DST, NRG-6, NRG-7a, SD-12, UZ#16	$1.6\text{-}3.4\times10^{-13}$ m^2 [0.16-0.34 D]	4.32 m^{-1} [1.32 ft^{-1}]	
	Calibrated Base Case	2.76×10^{-13} m^2 [0.280 D]		
Yucca Mountain Tptpll (tsw35) Deep Borehole Data	Uncalibrated	9.0×10^{-13} m^2 [0.91 D]	3.16 m^{-1} [0.96 ft^{-1}]	
	Calibrated Base Case	1.29×10^{-12} m^2 [1.31 D]		

Table 3-2. Comparison of properties estimated at Apache Leap Research Site and Yucca Mountain

	Apache Leap Research Site	YM Exploratory Studies Facility and Deep Boreholes (Tsw34)		YM Exploratory Studies Facility and Deep Boreholes (Tsw35)	
		Uncalibrated	Calibrated Base Case	Uncalibrated	Calibrated Base Case
Welding	slightly welded	moderately to densely welded			
Fracture Permeability, k_a	7.94×10^{-16} m^2 [8.05×10^{-4} D]	$1.6–3.4\times10^{-13}$ m^2 [0.16-0.34 D]	2.76×10^{-13} m^2 [0.280 D]	9.0×10^{-13} m^2 [0.91 D]	1.29×10^{-12} m^2 [1.31 D]
Fracture Permeability, k_w	7.24×10^{-16} m^2 [7.34×10^{-4} D]	No Data	No Data	No Data	No Data
Matrix Permeability, k_a	1.62×10^{-15} m^2 [1.64×10^{-3} D]	No Data	No Data	No Data	No Data
Matrix Permeability, k_w	5.62×10^{-16} m^2 [5.69×10^{-4} D]	7.5×10^{-19} m^2 [7.6×10^{-7} D]	4.07×10^{-18} m^2 [4.12×10^{-6} D]	3.1×10^{-17} m^2 [3.1×10^{-5} D]	3.04×10^{-17} m^2 [3.08×10^{-5} D]
Fracture Density, Tunnel Data with Length Threshold	Not Applicable	4.32 m^{-1} [1.32 ft^{-1}]		3.16 m^{-1} [0.96 ft^{-1}]	
Fracture Frequency in Borehole	0.77 m^{-1} [0.23 ft^{-1}]	2.7–5.0 m^{-1} [0.8–1.5 ft^{-1}] (boreholes in Table 3-3)		No Data	
Fracture Density in Borehole, Corrected	1.85 m^{-1} [0.56 ft^{-1}]	6.4–11.2 m^{-1} [2.0–3.4 ft^{-1}] (boreholes in Table 3-3)		No Data	
Fracture Porosity	1.7%	1.0%		1.1%	
Matrix Porosity	17.5%	11.0%		13.1%	
Fracture van Genuchten α	No Data	6.8×10^{-1} kPa^{-1} [4.7 psi^{-1}]	5.16×10^{-1} kPa^{-1} [3.56 psi^{-1}]	1.0 kPa^{-1} [6.9 psi^{-1}]	7.39×10^{-1} kPa^{-1} [5.10 psi^{-1}]
Matrix van Genuchten α	2.23×10^{-2} kPa^{-1} [1.54×10^{-1} psi^{-1}]	3.69×10^{-3} kPa^{-1} [2.54×10^{-2} psi^{-1}]	3.86×10^{-3} kPa^{-1} [2.66×10^{-2} psi^{-1}]	6.41×10^{-3} kPa^{-1} [4.42×10^{-2} psi^{-1}]	6.44×10^{-3} kPa^{-1} [4.44×10^{-2} psi^{-1}]
Klinkenburg Coefficient	3.22×10^2 kPa [46.7 psi]	Effect assumed negligible due to flow dominated by large aperture fractures			
Matrix Water Content	14.30%	9.3%		10.1%	
Dry Thermal Conductivity	1.27 J/m s K [0.73 Btu/ft h °F]	1.56 J/m s K [0.90 Btu/ft h °F]		1.20 J/m s K [0.69 Btu/ft h °F]	
Sat. Thermal Conductivity	1.82 J/m s K [1.05 Btu/ft h °F]	2.33 J/m s K [1.35 Btu/ft h °F]		2.02 J/m s K [1.17 Btu/ft h °F]	
Dry Rock Specific Heat	7.02×10^2 J/kg K [0.168 Btu/lb$_m$°F]	9.48×10^2 J/kg K [0.226 Btu/lb$_m$°F]		9.00×10^2 J/kg K [0.215 Btu/lb$_m$°F]	

IN-PROCESS ENTRIES

10/22/02

For the sake of the scientific record, Tables 3-1 and 3-2, as finally entered in the aforementioned TEF deliverable are reproduced on the following pages.

Table 3-1. Comparison of Apache Leap Research Site and Yucca Mountain Field-Estimated Air Permeabilities and Their Relationship to Fracture Density and Degree of Welding

		Fracture Permeability, k_a	Fracturing/ Fracture Density	Degree of Welding
Apache Leap Research Site X-, Y-, and Z-series boreholes		7.94×10^{-16} m^2 [8.05×10^{-4} D]	0.98–3.6 m^{-1} [0.30–1.1 ft^{-1}]	slightly welded
Yucca Mountain PTn	NRG–6, NRG–7a	——	3.1–2.7 m^{-1} [0.9–0.8 ft^{-1}]	nonwelded to partially welded
	ESF Alcove 4	1.00×10^{-13} m^2 [0.10 D]	discretely faulted and fractured	
	Uncalibrated Values (NRG–7a and Alcove 3)	$(0.16–3.20) \times 10^{-12}$ m^2 [0.16–3.24 D]		
	Calibrated Basecase	$(0.26–20) \times 10^{-12}$ m^2 [0.26–20 D]		
Yucca Mountain Tptpmn (tsw34) ESF Data	Alcove 6	1.26×10^{-12} m^2 [1.28 D]	highly fractured	moderately to densely welded
	Niche 35+66	1.00×10^{-13} m^2 [0.10 D]	brecciated; > Niche 36+50	
	Niche 36+50	3.98×10^{-14} m^2 [4.03×10^{-2} D]	moderately fractured; < Niche 35+66	
	Niche 31+07	3.98×10^{-14} m^2 [4.03×10^{-2} D]	moderately fractured	
	Niche 47+88	1.00×10^{-13} m^2 [0.10 D]	intensely fractured	
Yucca Mountain Tptpmn (tsw34) Deep Borehole Data	UZ–14, SD–7, SD–9, SD–12, NRG–6, NRG–7a	——	6.4–11.2 m^{-1} [2.0–3.4 ft^{-1}]	
	Uncalibrated Values (NRG–7a, NRG–6, SD–12, UZ#16, Alcove 5)	$(1.6 \text{ and } 3.4) \times 10^{-13}$ m^2 [0.16 and 0.34 D] (two weighted averages)	4.32 m^{-1} [1.32 ft^{-1}]	
	Calibrated Basecase	2.76×10^{-13} m^2 [0.280 D]		
Yucca Mountain Tptpll (tsw35) Deep Borehole Data	Uncalibrated Value (NRG–7a, UZ#16)	9.0×10^{-13} m^2 [0.91 D]	3.16 m^{-1} [0.96 ft^{-1}]	
	Calibrated Basecase	1.29×10^{-12} m^2 [1.31 D]		

Table 3-2. Comparison of Properties Estimated at Apache Leap Research Site and Yucca Mountain					
		Yucca Mountain Exploratory Studies Facility and Deep Boreholes (Tsw34)		Yucca Mountain Exploratory Studies Facility and Deep Boreholes (Tsw35)	
	Apache Leap Research Site	**Uncalibrated**	**Calibrated Basecase**	**Uncalibrated**	**Calibrated Basecase**
Welding	**Slightly Welded**	**Moderately to Densely Welded**			
Fracture Permeability, k_a	7.94×10^{-16} m² [8.05×10^{-4} D]	$(1.6–3.4) \times 10^{-13}$ m² [0.16–0.34 D] (two weighted averages)	2.76×10^{-13} m² [0.280 D]	9.0×10^{-13} m² [0.91 D]	1.29×10^{-12} m² [1.31 D]
Fracture Permeability, k_w	7.24×10^{-16} m² [7.34×10^{-4} D]	No Data	No Data	No Data	No Data
Matrix Permeability, k_a	1.62×10^{-15} m² [1.64×10^{-3} D]	No Data	No Data	No Data	No Data
Matrix Permeability, k_w	5.62×10^{-16} m² [5.69×10^{-4} D]	7.5×10^{-19} m² [7.6×10^{-7} D]	4.07×10^{-18} m² [4.12×10^{-6} D]	3.1×10^{-17} m² [3.1×10^{-5} D]	3.04×10^{-17} m² [3.08×10^{-5} D]
Fracture Density, Tunnel Data with Length Threshold	Not Applicable	4.32 m^{-1} [1.32 ft^{-1}]		3.16 m^{-1} [0.96 ft^{-1}]	
Fracture Frequency in Borehole	0.77 m^{-1} [0.23 ft^{-1}]	2.7–5.0 m^{-1} [0.8–1.5 ft^{-1}] (boreholes in Table 3-3)		No Data	
Fracture Density in Borehole, Corrected	1.85 m^{-1} [0.56 ft^{-1}]	6.4–11.2 m^{-1} [2.0–3.4 ft^{-1}] (boreholes in Table 3-3)		No Data	
Fracture Porosity	1.7%	1.0%		1.1%	
Matrix Porosity	17.5%	11.0%		13.1%	
Fracture van Genuchten α	No Data	6.8×10^{-1} kPa^{-1} [4.7 psi^{-1}]	5.16×10^{-1} kPa^{-1} [3.56 psi^{-1}]	1.0 kPa^{-1} [6.9 psi^{-1}]	7.39×10^{-1} kPa^{-1} [5.10 psi^{-1}]
Matrix van Genuchten α	2.23×10^{-2} kPa^{-1} [1.54×10^{-1} psi^{-1}]	3.69×10^{-3} kPa^{-1} [2.54×10^{-2} psi^{-1}]	3.86×10^{-3} kPa^{-1} [2.66×10^{-2} psi^{-1}]	6.41×10^{-3} kPa^{-1} [4.42×10^{-2} psi^{-1}]	6.44×10^{-3} kPa^{-1} [4.44×10^{-2} psi^{-1}]
Klinkenburg Coefficient	3.22×10^2 kPa [46.7 psi]	Effect assumed negligible due to flow dominated by large aperture fractures			
Matrix Water Content	14.30%	9.3%		10.1%	
Dry Thermal Conductivity	1.27 J/m s K [0.73 Btu/ft h °F]	1.56 J/m s K [0.90 Btu/ft h °F]		1.20 J/m s K [0.69 Btu/ft h °F]	
Sat. Thermal Conductivity	1.82 J/m s K [1.05 Btu/ft h °F]	2.33 J/m s K [1.35 Btu/ft h °F]		2.02 J/m s K [1.17 Btu/ft h °F]	
Dry Rock Specific Heat	7.02×10^2 J/kg K [0.168 Btu/lb_m°F]	9.48×10^2 J/kg K [0.226 Btu/lb_m°F]		9.00×10^2 J/kg K [0.215 Btu/lb_m°F]	

TITLE OF TASK 2:

Klinkenberg Correction to Apache Leap Research Site Matrix Air Permeability Data–Original Work by CNWRA Staff.

TASK 2 STAFF:

Cynthia L. Dinwiddie

DESCRIPTION OF TASK 2 OBJECTIVES AND THE APPROACH TAKEN TO ACHIEVE THE STATED OBJECTIVES:

Correct the Rasmussen, et al. (1990) laboratory-measured matrix air permeability data for the gas slippage phenomenon, provided their reported mean pore pressure and their estimated Klinkenberg coefficients. The results of this analysis will be incorporated into the final report "Geostatistical Analysis of Pneumatic, Hydraulic, and Thermal Properties of Unsaturated Fractured Rocks at the Apache Leap Research Site, a Yucca Mountain Analog" by Dinwiddie, Fedors, and Illman.

IN-PROCESS ENTRIES

10/22/02

A fundamental assumption of laminar flow theory is that fluids have a velocity equal to zero at solid surfaces; however, when the fluid is a gas, and a low-pressure gas in particular, negligible contact may occur between the gas molecules and the pore walls of a porous medium if the mean free path of the molecules is on the same order as the average pore diameter. In this event, the gas will flow with a higher velocity than that predicted by Darcy's law. The mean free path of a gas molecule is dependent on a number of factors, including temperature, pressure, and composition of the gas; for example, the mean free path of any gas molecule is shorter at high pressure than it is a low pressure. Klinkenberg (1941) observed that the apparent permeability of a porous medium to a gas is inversely proportional to the mean pore pressure, such that apparent gas permeability is not necessarily intrinsic to the porous medium.

The Klinkenberg relationship expresses the apparent gas permeability (k_g) in terms of the gas permeability at infinite pore pressure (k_∞), at which it behaves like a liquid, and as a function of the mean pore pressure (P_m) as follows:

$$k_g = k_\infty\left(1+\frac{b}{P_m}\right), \qquad (1)$$

where b is the Klinkenberg coefficient, or the gas slippage factor. Thus, if the Klinkenberg coefficient is negligible, the apparent gas permeability is equal to the intrinsic permeability of the medium. The Klinkenberg coefficient is frequently treated as a constant, while it in fact is composed of both porous medium and fluid properties (pore size; gas temperature, viscosity and molecular weight). Through empirical data analysis, the Klinkenberg coefficient is frequently expressed as a function of intrinsic permeability in the following manner:

$$b = Ck_{\infty}^{-n} \tag{2}$$

where C and n are curve fitting parameters. Thus, the gas-slippage phenomenon is more prominent in low permeability material and at low mean pore pressures. Rasmussen et al. (1990) estimated the matrix Klinkenberg coefficient point-by-point with Equation 1, given knowledge of the mean pore pressure during the air permeability tests (P_m = 108 kPa, with an average atmospheric pressure of 87 kPa [Illman and Neuman, 2001a; Vesselinov et al., 2001b]), the computed air permeability for an oven-dried core, k_g, and the computed liquid permeability for a completely saturated core, k_{∞}. It was explicitly assumed that the difference between the computed air and liquid permeability was caused by the Klinkenberg effect.

The gas slippage phenomenon, accounted for by the Klinkenberg coefficient, explains the prominent departure of the laboratory air permeability data from that of the laboratory liquid permeability data when liquid permeability data are plotted versus air permeability data from both field and laboratory measurements (see CNWRA SN No. 432, c/o R.W. Fedors). The data are shifted below the 1:1 correlation line, indicating that the laboratory air permeability measurements overpredict the liquid permeability of the matrix core samples, as is typical for low permeability granular porous media, particularly at low pore pressures. Figures 1 and 2 demonstrate a method used by Center staff to correct the Apache Leap Research Site matrix air permeability data for the gas slippage effect. The Klinkenberg coefficient (determined point-by-point by Rasmussen, et al. [1990] from matrix air and liquid permeability data utilizing Equation 1) is plotted versus the matrix liquid permeability data. While the data appear highly scattered on the logarithmic scale, one may still fit to them a curve in the form of Equation 2, resulting in the following empirical relationship between Klinkenberg coefficient and liquid permeability:

$$b = 0.5263k_{\infty}^{-0.1747} \tag{3}$$

Equation 3 was determined using the software Microsoft Excel 97 SR-2, installed on ATLANTIS, a CNWRA desk-top computer. Microsoft Excel 97 SR-2 has an automatic trendline fitting option, through which it calculates the least squares fit through the data using Equation 2 (i.e., power) and solves for the constants.

Assigning the empirically-determined Klinkenberg coefficient associated with a given matrix liquid permeability measurement location to the matrix air permeability measurement at the same location then allows this coefficient to be employed in Equation 1, such that the intrinsic permeability corrected for gas slippage may be determined from the measured matrix air permeability, by rearranging as follows:

$$k_{\infty} = \frac{k_g}{1 + \dfrac{b}{P_m}} \tag{4}$$

Liquid permeability data are plotted versus corrected air permeability data from laboratory measurements in Figure 3; the data fall, on the average, on the 1:1 correlation line. Correcting the air permeability data with the Klinkenberg coefficient results in an overall lowering of the indicated air permeability, as expected given the effect of the gas slippage phenomenon.

Data supporting this correction to ALRS matrix air permeability measurements are located in Table 2-1, where the 2 refers to the SN task number, not a chapter in the aforementioned deliverable. Column A is the borehole identifier, while Columns B through D provide Cartesian coordinates for the measurements. Columns E through G provide data reported in Rasmussen, et al. (1990) by University of Arizona researchers. Figures 1 and 2 are plots of Column G versus Column F (ALRS-estimated Klinkenberg coefficient versus ALRS-measured liquid matrix permeability). Figures 1 and 2 also illustrate the result of the MS Excel power least squares regression; the computed Klinkenberg coefficients determined by CNWRA staff using Equation 3 with the data in Column F are in Column H. Finally, within Column I are the CNWRA-corrected air permeability data, obtained by using the CNWRA-computed Klinkenberg coefficient of Column H, the ALRS-measured air permeability data (Column E) and Equation 4. Figure 3 is then a plot of Column F versus Column I (i.e., the ALRS-measured matrix liquid permeability versus the CNWRA gas slippage corrected matrix air permeability).

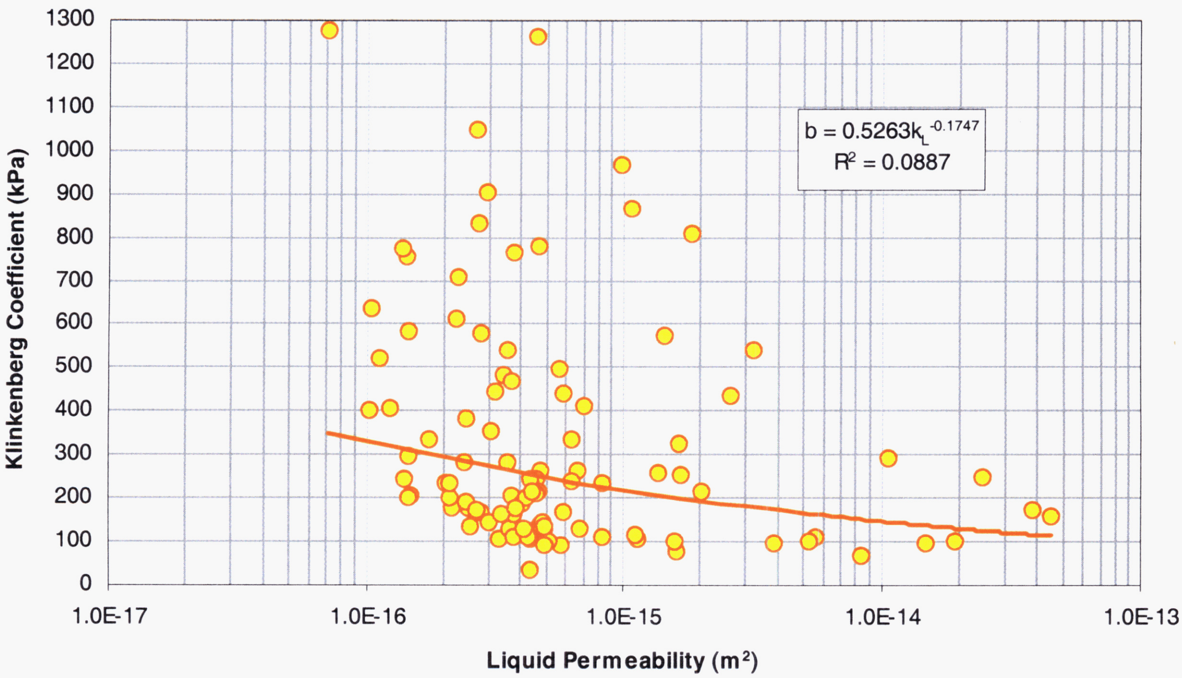

Figure 1. Klinkenberg coefficient as a function of laboratory-measured matrix liquid permeability on a logarithmic scale.

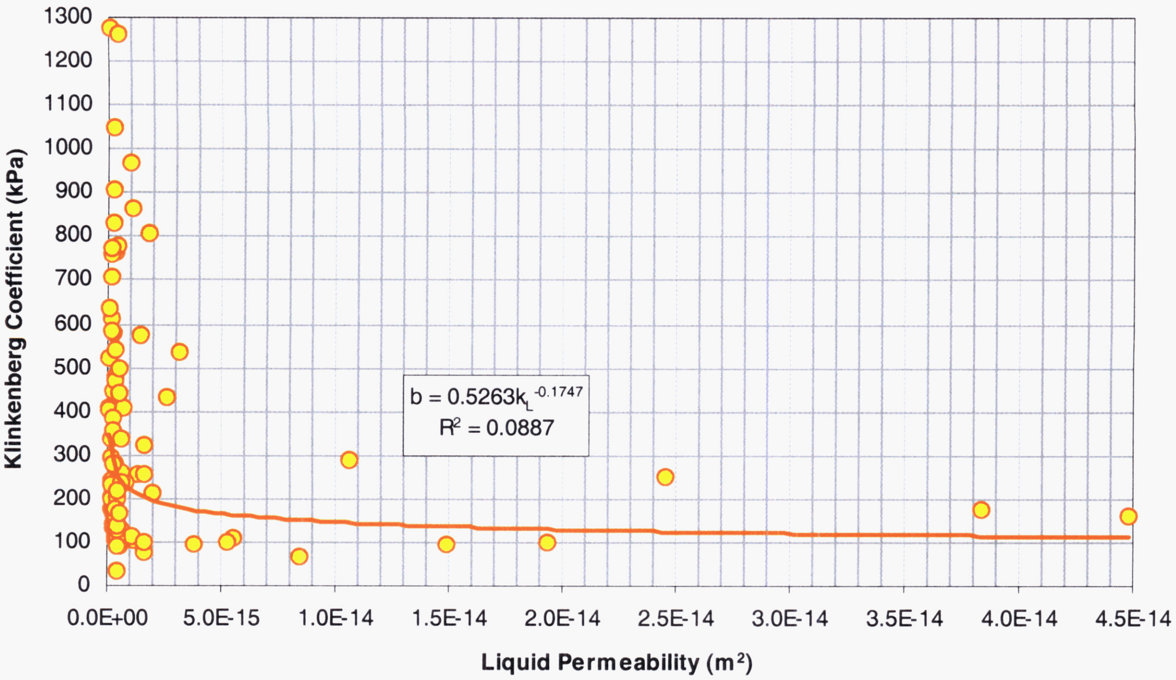

Figure 2. Klinkenberg coefficient as a function of laboratory-measured matrix liquid permeability.

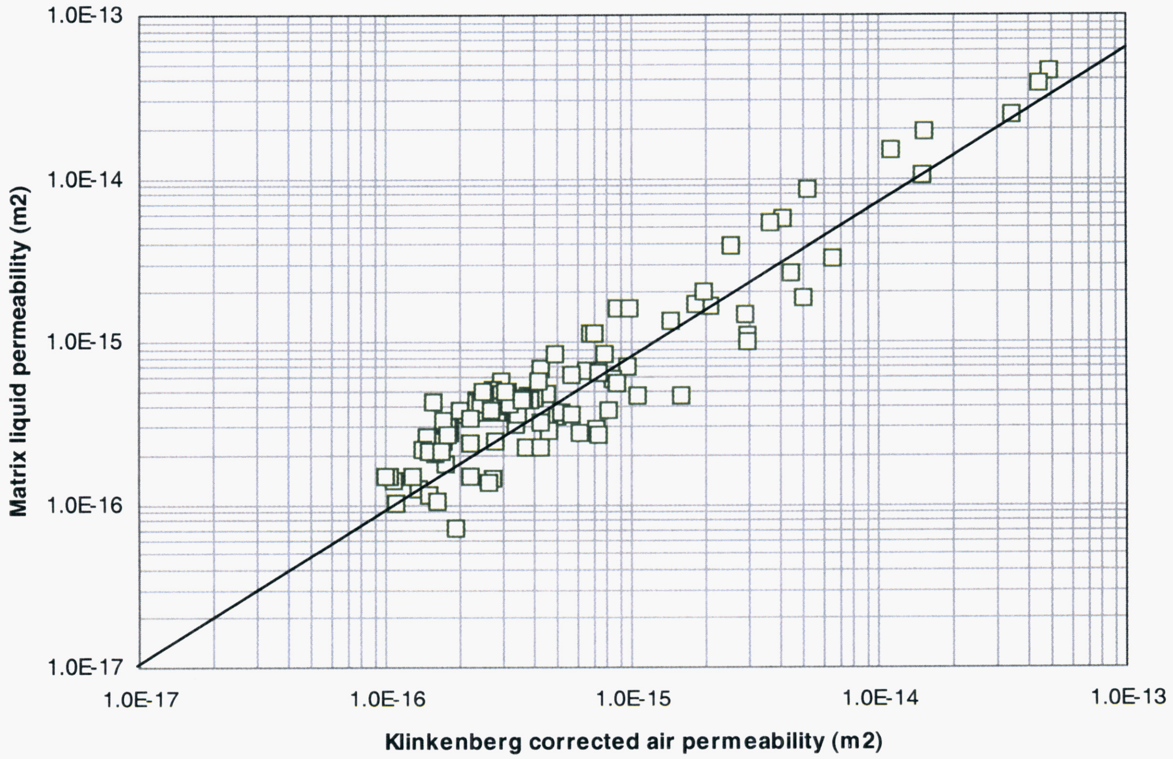

Figure 3. Laboratory-measured matrix liquid permeability versus laboratory-measured matrix air permeability corrected for the gas slippage phenomenon (note: mean pore pressure was 108 kPa).

Table 2-1. Data supporting gas slippage correction of ALRS laboratory-measured matrix air permeability								
A	B	C	D	E	F	G	H	I
Borehole	x (m)	y (m)	z (m)	ALRS Lab air permeability (m^2)	ALRS Lab H_2O permeability (m^2)	ALRS Klinkenberg coefficient (kPa)	CNWRA Klinkenberg coefficient (kPa)	CNWRA Corrected Air Permeability (m^2)
X1	8.84	10.04	-1.46	8.43E-15	1.46E-15	575	205.60	2.90E-15
	8.2	10.04	-2.10	1.51E-15	4.80E-16	264	249.70	4.56E-16
	7.64	10.04	-2.67	1.36E-15	2.24E-16	613	285.26	3.73E-16
	5.44	10.04	-4.86	5.35E-16	1.23E-16	408	316.76	1.36E-16
	3.25	10.04	-7.05	4.40E-16	1.02E-16	401	327.29	1.09E-16
	1.34	10.04	-8.96	4.17E-16	1.41E-16	242	309.29	1.08E-16
	-0.85	10.04	-11.15	3.98E-16	1.50E-16	206	305.96	1.04E-16
X2	19.17	10.03	-1.29	2.55E-14	1.49E-14	95	137.02	1.12E-14
	18.46	10.03	-2.00	1.71E-15	3.43E-16	481	264.80	4.95E-16
	17.97	10.03	-2.49	1.35E-15	4.57E-16	243	251.85	4.05E-16
	15.77	10.03	-4.68	8.19E-16	7.05E-17	1277	349.10	1.94E-16
	13.37	10.03	-7.09	6.03E-16	2.51E-16	176	279.65	1.68E-16
	11.46	10.03	-9.00	2.50E-15	1.61E-15	76	202.12	8.71E-16
	9.06	10.03	-11.40	2.04E-15	1.14E-15	104	214.68	6.83E-16
	7.36	10.03	-13.10	6.63E-15	3.84E-15	97	173.64	2.54E-15
	5.17	10.03	-15.29	9.94E-16	4.94E-16	130	248.45	3.01E-16
	2.97	10.03	-17.48	1.35E-15	6.75E-16	129	235.26	4.25E-16
	0.71	10.03	-19.74	1.52E-15	8.31E-16	108	226.87	4.90E-16
	-1.34	10.03	-21.79	6.51E-16	2.79E-16	168	274.53	1.84E-16
X3	29.15	10.04	-1.23	3.07E-15	7.04E-16	409	233.54	9.71E-16
	28.52	10.04	-1.87	1.27E-15	4.70E-16	213	250.62	3.82E-16
	27.74	10.04	-2.64	2.76E-15	3.75E-16	765	260.71	8.08E-16
	25.62	10.04	-4.76	1.63E-15	2.81E-16	577	274.19	4.61E-16
	23.43	10.04	-6.96	2.17E-15	2.74E-16	831	275.40	6.11E-16
	21.31	10.04	-9.08	1.48E-15	3.17E-16	445	268.47	4.25E-16
	19.25	10.04	-11.13	9.92E-16	4.75E-16	139	250.16	2.99E-16
	17.13	10.04	-13.25	9.51E-16	5.71E-16	89	242.24	2.93E-16
	15.15	10.04	-15.23	6.30E-16	2.98E-16	143	271.39	1.79E-16
	12.96	10.04	-17.42	6.00E-16	3.32E-16	106	266.31	1.73E-16
	10.84	10.04	-19.54	5.27E-16	2.56E-16	135	278.69	1.47E-16
	8.51	10.04	-21.88	6.01E-16	2.09E-16	232	288.74	1.64E-16
	6.6	10.04	-23.79	9.04E-16	5.16E-16	100	246.57	2.75E-16
	4.33	10.04	-26.05	7.20E-16	3.82E-16	115	259.86	2.11E-16
	2.21	10.04	-28.17	8.50E-16	4.43E-16	119	253.23	2.54E-16
	0.09	10.04	-30.29	5.20E-16	2.17E-16	176	286.85	1.42E-16
Y1	8.93	5.08	-1.30	6.59E-16	1.77E-16	335	297.24	1.76E-16
	7.87	5.08	-2.36	3.52E-15	4.71E-16	777	250.53	1.06E-15
	7.3	5.08	-2.93	1.78E-15	3.66E-16	468	261.81	5.20E-16
	5.54	5.08	-4.69	6.02E-16	1.13E-16	521	321.48	1.51E-16
	3.2	5.08	-7.03	6.56E-16	1.04E-16	637	326.18	1.63E-16
	1.58	5.08	-8.65	4.99E-16	1.47E-16	294	307.05	1.30E-16
	-0.9	5.08	-11.13	6.18E-16	2.45E-16	190	280.83	1.72E-16
Y2	18.76	5.20	-1.58	6.01E-15	1.65E-15	325	201.25	2.10E-15
	17.7	5.20	-2.64	1.42E-14	1.83E-15	808	197.64	5.02E-15
	17.14	5.20	-3.21	1.56E-15	2.27E-16	708	284.60	4.29E-16
	15.65	5.20	-4.69	2.51E-15	2.94E-16	904	272.03	7.13E-16
	13.46	5.20	-6.88	5.88E-16	2.04E-16	234	289.96	1.60E-16
	11.34	5.20	-9.00	2.10E-15	1.12E-15	114	215.35	7.01E-16
	9.22	5.20	-11.12	9.74E-16	3.71E-16	204	261.19	2.85E-16
	6.95	5.20	-13.39	1.25E-14	8.44E-15	67	151.32	5.21E-15
	4.97	5.20	-15.37	8.39E-16	4.29E-16	123	254.65	2.50E-16

A	B	C	D	E	F	G	H	I
Borehole	x (m)	y (m)	z (m)	ALRS Lab air permeability (m^2)	ALRS Lab H_2O permeability (m^2)	ALRS Klinkenberg coefficient (kPa)	CNWRA Klinkenberg coefficient (kPa)	CNWRA Corrected Air Permeability (m^2)
Y2 (cont.)	2.71	5.20	-17.63	7.81E-16	4.34E-16	105	254.13	2.33E-16
	0.73	5.20	-19.61	7.26E-16	3.62E-16	130	262.32	2.12E-16
	-1.39	5.20	-21.73	9.85E-16	4.76E-16	137	250.07	2.97E-16
Y3	28.65	5.35	-1.68	2.72E-15	5.88E-16	439	241.00	8.42E-16
	27.88	5.35	-2.46	8.84E-15	1.08E-15	865	216.72	2.94E-15
	27.17	5.35	-3.17	1.74E-14	3.19E-15	538	179.36	6.54E-15
	25.68	5.35	-4.65	7.40E-14	2.45E-14	250	125.62	3.42E-14
	23.49	5.35	-6.84	1.05E-15	1.43E-16	757	308.53	2.72E-16
	21.3	5.35	-9.03	1.01E-13	4.48E-14	160	113.05	4.93E-14
	18.75	5.35	-11.58	4.20E-15	1.36E-15	257	208.16	1.43E-15
	17.2	5.35	-13.14	6.91E-16	3.77E-16	109	260.46	2.03E-16
	14.94	5.35	-15.40	5.25E-16	4.33E-16	35	254.24	1.57E-16
	12.96	5.35	-17.38	6.30E-16	2.69E-16	170	276.28	1.77E-16
	10.69	5.35	-19.64	7.92E-16	4.31E-16	109	254.44	2.36E-16
	8.64	5.35	-21.69	8.49E-16	3.72E-16	162	261.07	2.48E-16
	6.59	5.35	-23.74	5.49E-16	2.10E-16	202	288.50	1.50E-16
	4.26	5.35	-26.08	9.95E-16	4.02E-16	185	257.56	2.94E-16
	2.28	5.35	-28.06	8.21E-16	4.10E-16	130	256.67	2.43E-16
	0.3	5.35	-30.04	3.81E-16	1.47E-16	199	307.05	9.91E-17
Z1	20.79	0.00	-1.60	2.86E-15	5.61E-16	497	242.99	8.80E-16
	21.64	0.00	-2.45	1.95E-15	3.56E-16	541	263.08	5.68E-16
	22.35	0.00	-3.16	3.55E-14	1.06E-14	290	145.42	1.51E-14
	23.69	0.00	-4.50	5.31E-15	4.60E-16	1260	251.56	1.59E-15
	26.02	0.00	-6.83	1.01E-15	2.44E-16	382	281.03	2.80E-16
	28.29	0.00	-9.10	1.20E-14	2.63E-15	434	185.51	4.42E-15
	30.34	0.00	-11.15	2.60E-15	2.67E-16	1047	276.64	7.30E-16
Z2	11.21	0.03	-1.61	8.56E-16	1.47E-16	584	307.05	2.23E-16
	11.92	0.03	-2.32	1.19E-15	3.05E-16	356	270.29	3.40E-16
	12.63	0.03	-3.02	5.16E-15	1.68E-15	255	200.62	1.81E-15
	14.4	0.03	-4.79	1.03E-15	4.88E-16	142	248.98	3.12E-16
	16.38	0.03	-6.77	1.02E-14	5.57E-15	108	162.72	4.07E-15
	18.57	0.03	-8.96	9.16E-14	3.84E-14	174	116.13	4.41E-14
	20.62	0.03	-11.01	8.97E-15	9.88E-16	967	220.11	2.95E-15
	23.02	0.03	-13.42	1.29E-15	4.36E-16	242	253.93	3.85E-16
	24.86	0.03	-15.26	1.18E-15	3.58E-16	282	262.83	3.44E-16
	27.12	0.03	-17.52	6.14E-16	2.13E-16	232	287.78	1.68E-16
	29.17	0.03	-19.57	1.23E-15	4.57E-16	210	251.85	3.69E-16
	31.37	0.03	-21.76	2.41E-15	8.31E-16	236	226.87	7.77E-16
Z3	1.41	0.00	-1.41	1.02E-15	1.37E-16	774	310.85	2.63E-16
	2.12	0.00	-2.12	2.09E-15	6.69E-16	262	235.63	6.57E-16
	2.69	0.00	-2.69	3.38E-14	1.94E-14	99	130.84	1.53E-14
	4.67	0.00	-4.67	9.23E-15	5.31E-15	98	164.08	3.66E-15
	6.93	0.00	-6.93	7.92E-16	2.41E-16	281	281.64	2.20E-16
	8.98	0.00	-8.98	2.82E-15	1.60E-15	101	202.34	9.81E-16
	11.17	0.00	-11.17	5.50E-15	2.03E-15	213	194.09	1.97E-15
	13.29	0.00	-13.29	1.08E-15	4.16E-16	199	256.02	3.20E-16
	15.27	0.00	-15.27	7.66E-16	3.38E-16	161	265.48	2.22E-16
	17.47	0.00	-17.47	8.24E-16	4.93E-16	90	248.54	2.50E-16
	19.59	0.00	-19.59	1.02E-15	4.92E-16	136	248.63	3.09E-16
	21.71	0.00	-21.71	9.14E-16	3.80E-16	177	260.10	2.68E-16
	23.83	0.00	-23.83	2.37E-15	6.35E-16	335	237.79	7.40E-16
	26.02	0.00	-26.02	1.35E-15	5.81E-16	168	241.51	4.17E-16
	28.07	0.00	-28.07	1.83E-15	6.27E-16	237	238.31	5.71E-16
	30.33	0.00	-30.33	1.21E-15	4.40E-16	217	253.53	3.61E-16

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CONCURRENCE:

"I have reviewed this scientific notebook and find it in agreement with QAP-001. There is sufficient information regarding methods used for conducting tests, acquiring and analyzing data so that another qualified individual could repeat the activity."

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ADDITIONAL INFORMATION FOR SCIENTIFIC NOTEBOOK NO. 514E

Document Date:	3/29/2002
Availability:	Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road San Antonio, Texas 78228
Contact:	Southwest Research Institute® Center for Nuclear Waste Regulatory Analyses 6220 Culebra Road San Antonio, TX 78228-5166 Attn.: Director of Administration 210.522.5054
Data Sensitivity:	■"Non-Sensitive" ☐ Sensitive ☐"Non-Sensitive - Copyright" ☐ Sensitive - Copyright
Date Generated:	04/08/2003
Operating System: (including version number)	Windows NT Ver. 4.00
Application Used: (including version number)	Atlantis, Excel 97SR2, WordPerfect
Media Type: (CDs, 3 1/2, 5 1/4 disks, etc.)	1 - CD
File Types: (.exe, .bat, .zip, etc.)	xls, wpd
Remarks: (computer runs, etc.)	Media contains the electronic notebook