YMP	**Scientific Analysis/Calculation Error Resolution Document** *Complete only applicable items.*	QA: QA Page 1 of 5

INITIATION

1. Originator: Paul Reimus	2. Date: 4/22/08	3. ERD No. ANL-NBS-HS-000031 ERD 01 ~~Draft D~~ 5/27/08
4. Document Identifier: ANL-NBS-HS-000031 REV02 ACN01	5. Document Title: Saturated Zone Colloid Transport	

6. Description of and Justification for Change (Identify applicable CRs and TBVs):

I Background Information Summary

This ERD is prepared to resolve CRs associated with *Saturated Zone Colloid Transport*, ANL-NBS-HS-000031 REV02 ACN 01 (see below). There are no open TBVs associated with this document.

CR 10532: The data points associated with "Schijven MS-2" and "Schijven PRD-1" in Figure 6-4 of ANL-NBS-HS-000031 REV 02 are not correct. This error occurred because the wrong column of information from the source data spreadsheet was plotted. The correct data was used in all the analyses contained in the spreadsheet, so the error applies only to the plot itself, and it does not affect any of the conclusions of the analysis report.

CR 11155: Errors affecting ANL-NBS-HS-000031 REV 02 were found in DTN LA0301AA831352.001. The tritium concentrations for "Run 1 Column A" were associated with the wrong cumulative sample collection weights, causing the tritium breakthrough curve to be shifted to earlier times and smaller volumes than it should have been. When this error is corrected, the tritium breakthrough curve relative to the colloid breakthrough curves in this run/column is much more consistent with the behavior observed in the other runs and columns reported in DTN LA0301AA831352.001. The error associated with the tritium breakthrough curve in Run 1 Column A is reflected in Figure 6-17 the analysis report, so this figure is revised. Also, the tritium model curve in Figure 6-17 and the transport parameters (RELAP model parameters) for tritium and the colloids in the column labeled "6.01, Col. C" of Table 6-16 are revised. These new transport parameters are reflected in a revision to DTN LA0303PR831361.001, which contains the RELAP model analyses of the data in LA0301AA831352.001.

(see attached)

CONCURRENCE

	Printed Name	Signature	Date
7. Checker	Hari Viswanathan	[signature]	5/16/2008
8. QCS/QA Reviewer	Peter Persoff	[signature]	5/19/2008

APPROVAL

	Printed Name	Signature	Date
9. Originator	Paul Reimus	[signature]	5/16/2008
10. Responsible Manager	Paul Dixon	[signature]	5-22-08

(Continued from Block 6)

CR 11832: This CR was generated as a result of an impact review (IRAN 6187) of the revision to DTN LA0303PR831361.001. The impacts identified in IRAN 6187 are identical to the impacts listed above for CR 11155 (i.e., changes to Figure 6-17 and Table 6-16 of ANL-NBS-HS-000031 REV02 ACN 01). Thus, addressing CR 11155 also addresses CR 11832.

The errors identified in CRs 10532, 11155, and 11832 are analyzed herein for potential impact on the parent report as well as the following technical products that use the information from the parent report.

ANL-NBS-HS-000039 REV 02, ACN 02, *Saturated Zone In-Situ Testing*
ANL-NBS-MD-000001 REV 04, *Features, Events, and Processes in UZ Flow and Transport*
ANL-NBS-MD-000002 REV 04, *Features, Events, and Processes in SZ Flow and Transport*
MDL-EBS-PA-000004 REV 03, *Waste Form and In-Drift Colloids-Associated Radionuclide Concentrations: Abstraction and Summary*
MDL-NBS-HS-000008 REV 02 ADD 01, *Radionuclide Transport Models under Ambient Conditions*
MDL-NBS-HS-000010 REV 03, ACN 01, *Site-Scale Saturated Zone Transport*
MDL-NBS-HS-000020 REV 02, ADD 02, *Particle Tracking Model and Abstraction of Transport Processes*
MDL-NBS-HS-000021 REV 03, ADD 01, *Saturated Zone Flow and Transport Model Abstraction*
ANL-WIS-MD-000027 REV 00, *Features, Events, and Processes for the Total System Performance Assessment: Analyses*
MDL-WIS-PA-000005 REV 00, *Total System Performance Assessment Model/Analysis for the License Application*
MDL-WIS-PA-000005 REV 00, ADD 01, *Total System Performance Assessment Model/Analysis for the License Application*
TDR-WIS-PA-000014 REV 00, *TSPA Information Package for the Draft SEIS*

The analyses and updates to resolve CRs 10532, 11155, and 11832 have only two minor impacts on downstream technical products: The fraction of colloids transporting with no retardation through the natural barrier system (i.e., the colloid "fast fraction") should be 0.00170 instead of 0.00168, and the transport time associated with this colloid fast fraction should be 50 years instead of 100 years. These impacts apply only to MDL-WIS-PA-000005 REV 00, ADD 01, *Total System Performance Assessment Model/Analysis for the License Application*, and they do not impact the overall performance assessment results or conclusions (See Section III.2). There are no impacts on any of the other downstream products listed above.

This ERD also incorporates colloid transport data obtained from field testing in the saturated alluvium at NC-EWDP Site 22 (DTN: LA0701PR150304.002), which occurred after ANL-NBS-HS-000031 REV 02 ACN 01 was issued. The incorporation of these data has no impact on downstream technical products.

II Inputs and/or Software

Direct inputs to this error resolution analysis (to address both CRs) include the following DTNs: LA0711PR150304.004 [DIRS 185425]; LA0303PR831361.001 [DIRS 184301], and LA0701PR150304.002 [DIRS 185424]. These DTNs are qualified as shown in the TDMS.

Attachment A documents this error resolution analysis. It is written in the format of a data package that can be compared with the contents of the three output DTNs of the parent analysis report: LA0303HV831352.002, LA0303HV831352.003, and LA0303HV831352.004. The attachment documents how the contents of these existing DTNs would be updated if they were to be superseded. The content changes are shown in Section IV.2 of this ERD to have negligible impact on the TSPA. The impact on the parent report of the changes shown in Attachment A are documented in Attachment B, with all changes (relative to the parent report) highlighted in yellow.

RELAP V2.0 (STN: 10551-2.0-00) [DIRS 159065] was used in this analysis to complete the update to DTN: LA0303PR831361.001 [DIRS 184301] and also to complete the analysis contained in the DTN: LA0701PR150304.002 [DIRS 185424].

III Analysis and Results

This section provides an analysis of the impact of CRs 10532, 11155, and 11832. As a result, certain pages of the parent report ANL-NBS-HS-000031 REV 02 ACN 01 should be corrected with the updated information. Attachment A shows these changes which are highlighted in yellow. The most important pages of Attachment A for assessing the impacts of CRs 10532, 11155, and 11832 are pages 6-11[a], 6-14[a], 6-17[a], 6-18[a], 6-19[a], 6-45[a], and 6-47[a].

III.1 Analysis of CR 10532

CR 10532 identified what was strictly a plotting error in Figure 6-4 of ANL-NBS-HS-000031 REV 02 ACN 01. There are no impacts to the analyses in ANL-NBS-HS-000031 REV 02 ACN 01 or to any downstream technical products because this error was not propagated to the analyses. The correct data were used in all the analyses in ANL-NBS-HS-000031 REV 02 ACN 01.

III.2 Analysis of CRs 11155 and 11832

Resolution of CRs 11155 and 11832 resulted in the supersession of DTN: LA0301AA831352.001 by DTN: LA0711PR150304.004 and in the revision of DTN: LA0303PR831361.001. However, these DTN changes have negligible impact on the distributions of colloid retardation factors in the fractured volcanics and alluvium, and they also have a negligible impact on the fraction of colloids transporting with no retardation through the natural barrier system. A complete evaluation of these impacts is provided in Section IV.2. The revised analysis of the colloid retardation factor distributions and the fraction of colloids transporting with no retardation are contained in Attachments A and B of this ERD.

IV Impact Evaluation

IV.1 Impact Evaluation of CR 10532

The plotting error identified in CR 10352 is corrected as shown in Figure 6-4 of Attachment A. Because correct data were used in all the analyses in ANL-NBS-HS-000031 REV 02 ACN 01, the correction to the figure has no impacts to the analyses in ANL-NBS-HS-000031 REV 02 ACN 01 or to any downstream technical products.

IV.2 Impact Evaluation of CRs 11155 and 11832

MDL-WIS-PA-000005 REV 00, ADD 01, *Total System Performance Assessment Model/Analysis for the License Application*, is the only downstream product impacted by CRs 11155 and 11832. An impact evaluation follows.

CRs 11155 and 11832 are concerned with the same issues, so their impacts are evaluated together in this section. The supersession of DTN: LA0301AA831352.001 with DTN: LA0711PR150304.004 and the revision of DTN: LA0303PR831361.001 affect the distributions used for colloid retardation factors in both the saturated volcanics and alluvium. These distributions are reflected in the parameters CORVO and CORAL, respectively (described in more detail in MDL-NBS-HS-000021 REV 03 ADD 01). The impacts of the changes to the DTNs on these distributions are shown to be negligible in Figures 6-3 and 6-6 in Attachment B (data contained in Attachment A). Whereas previously all of the probabilities associated with the "truncated CDF" data points on these figures fell at or below the probabilities associated with the simplified "TSPA CDF" curves, a few of the "truncated CDF" points in Figure 6-6 (alluvium) now lie above the "TSPA CDF" curve. However, it is apparent that the TSPA CDF curve still represents the data very well, and none of the data points lie above the TSPA CDF curve until colloid retardation factors exceed about 150. The TSPA CDF curve conservatively overestimates the probabilities of retardation factors less than 150, and it is these smaller retardation factors that ultimately have a bigger impact on dose calculations. Thus, it is concluded that the impact on the colloid retardation factor distributions, CORVO and CORAL, is negligible.

The supersession of DTN: LA0301AA831352.001 with DTN: LA0711PR150304.004 and the revision of DTN: LA0303PR831361.001 also affect the fraction of colloids transporting with no retardation, which is discussed in Section 6.6 of ANL-NBS-HS-000031 REV 02 ACN 01. A revised analysis discussion is provided in Section 6.6 of Attachment B (data contained in Attachment A). The revised analysis shows that the fraction of colloids transporting with no retardation is 0.00170 for an associated combined transport time in the fractured volcanics and alluvium of 50 years. In the original document, and in MDL-WIS-PA-000005 REV 00, ADD 01, *Total System Performance Assessment Model/Analysis for the License Application*, the fraction of colloids with no retardation is 0.00168 and the associated combined transport time is 100 years. Thus, both the colloid fast fraction and the associated travel time are different in the revised analysis as compared to the TSPA. However, the difference in the fast fraction is only 1.2%, which is negligible given all the uncertainties associated with the estimation of the fast fraction (see parent analysis report). Furthermore, this difference would disappear if the two values were rounded to two significant figures, which is considered entirely appropriate. The associated transport time was decreased from 100 years to 50 years so that the fast fraction would remain approximately the same as in the original analysis report and in the TSPA. The original transport time of 100 years was conservatively chosen to be somewhat less than the median transport time in the saturated zone, so the selection of an equally arbitrary 50-year transport time does not constitute any loss of defensibility, and in fact, it adds to the conservatism in the fast fraction estimate because the fraction increases as transport times decrease. The revised analysis would yield a fast fraction of 0.00126 if the transport time were kept at 100 years, and the corresponding impact on TSPA would be a reduction in dose associated with the transport of unretarded colloids that have irreversibly-sorbed radionuclides. Thus, given all the uncertainties in the estimate of the colloid fast fraction and the fact that the revised analysis yields a smaller fast fraction for the transport time assumed in the TSPA, it is concluded that there is negligible impact of the revised analysis on the TSPA.

As stated in Section III, the most important pages of Attachment A for assessing the impacts of CRs 11155, and 11832 are pages 6-11[a], 6-14[a], 6-17[a], 6-18[a], 6-19[a], 6-45[a], and 6-47[a].

Attachment A
Saturated Zone Colloid Retardation Factors and Rate Constants for the SZ Colloid Transport Analysis Report

The following material is equivalent to a Readme file for the spreadsheet data that is provided on pages A-4 to A-22:

Applicable Parameters/Parameter Numbers:
COLLOID ATTACHMENT RATE CONSTANT - 6976
COLLOID RETARDATION FACTOR -6991

Inputs:
DTN: LA0303PR831231.003 (C-wells field tracer test interpretations)
DTN: LA0303PR831352.002 (ER-20-5 field tracer test interpretations)
DTN: LA0403PR831352.001 (Laboratory NTS fracture tracer test interpretations)
DTN: LA0303PR831361.001 (Laboratory alluvium tracer test interpretations)
DTN: LA0701PR150304.002 (NC-EWDP Site 22 tracer test interpretations)

Schijven, J.F.; Hoogenboezem, W.; Hassanizadeh, S.M.; and Peters, J.H. 1999. "Modeling Removal of Bacteriophages MS2 and PRD1 by Dune Recharge at Castricum, Netherlands." *Water Resources Research,* 35(4), 1101-1111. Washington, D.C.: American Geophysical Union. TIC: 252295.

Summary: This supporting material (equivalent to a data package) consists of a spreadsheet that contains 4 worksheets. The contents of each worksheet are described below.

Worksheet "Volcanics Data" – Contains compilations of filtration/attachment rate constant data and retardation factor data from laboratory and field tracer tests conducted in saturated fractured volcanics from the Nevada Test Site. Cells A1:E11 contain data from field tracer tests. Sources of data are listed in cells F4:G11 (note that the "C-Wells BF" data come from the "Bullfrog_Spheres_Relap.xls" spreadsheet in DTN LA0303PR831231.003, and the "C-Wells PP" data come from the "Prow_Pass_Spheres_Relap.xls" spreadsheet in DTN LA0303PR831231.003; also, note that the detachment rate constants in column C are calculated as k_{filt}/(R-1) or Cx = Bx/(Dx-1), where x is the row number). To the right of these data, in cells I2:N11, are the filtration rate constants and retardation factors for individual pathways or individual microspheres at the C-wells. Sources of these data are listed in cells O4:P11. The entries in column N represent incremental mass fractions that are associated with a single C-wells colloid response that was interpreted as being a result of multiple retardation factors (the corresponding retardation factor is listed in ascending order in column M). For instance, the second microsphere peak in the Bullfrog tracer test was interpreted as being the result of the three mass fractions (0.117, 0.183, and 0.7 - summing to 1.0) with retardation factors of 1.19, 6.3 and 200, respectively. The mass fraction values in column N are used as multipliers in column AG to ensure that multiple retardation factors derived from a single microsphere response are weighted appropriately in the overall CDF for retardation factors. Thus, instead of assigning each of the 3 retardation factors mentioned above the full incremental probability for field test data (0.05263), each retardation factor is assigned an incremental probability of 0.05263 *multiplied by* the corresponding mass fraction so that the sum of the incremental probabilities for the three retardation factors equals 0.05263 (in column AG). Laboratory data in fractured volcanics are provided in cells A16:D45, with the type of colloid listed in cells E16:E45, and the data sources listed in cells G16:G45. The yellow-shaded cells in rows 44 and 45 were not used for development of distributions because the residence times were deemed too short to allow a meaningful estimation of filtration rate constants or retardation factors. Cells R1:S41 list the filtration rate constants and associated cumulative probabilities of all the data in ascending order (note that cells S3 and S4 contain the incremental cumulative probabilities associated with field data and lab data, respectively; and the actual probability distribution starts in row 5 of these two columns). Cells T1:U41 list the logarithms of the values in cells R1:S41. Cells W37:AA41 provide estimated filtration rate constants associated with observations at the NTS ER-20-5 wells using various assumptions, as discussed in Section 6.4.2 of the parent report. All retardation factors and their associated cumulative probabilities (called "raw data" in the parent report) are listed in cells AF1:AG41 (note that cells AG3 and AG4 contain the incremental cumulative probabilities associated with field data and lab data, respectively; and the actual probability distribution starts in row 5 of these two columns). The associated "truncated data" are listed in cells AI1:AJ41; and the associated data for the "TSPA cumulative distribution function" are listed in cells AL1:AM10. In all cases, field estimates of rate constants or retardation factors are given twice the probability weighting as laboratory estimates. There are 4 plots in the "Volcanics Data" worksheet. The plot in columns B through K near the bottom of the worksheet shows the filtration rate constants (hr^{-1}) vs. travel time (hrs). The plot in columns V through AE near the top of the spreadsheet shows the log of cumulative probability vs. log filtration rate constant (hr^{-1}). The uppermost plot in columns AO through AV shows cumulative probability vs. retardation factor for the "raw data", "truncated data", and "TSPA data", respectively. Finally, the lower plot in columns AO through AX shows cumulative probability vs. retardation factor for just the "truncated data." All plots except the uppermost one in columns AO through AV appear in this Error Resolution Document (ERD).

Worksheet "Alluvium Data" – Contains compilations of filtration/attachment rate constant data and retardation factor data from laboratory and field tracer tests conducted in saturated alluvium at the Nevada Test Site. The worksheet also contains a compilation of bacteriophage filtration/attachment rate constant data and retardation factor data from a sandy alluvial aquifer in The Netherlands (Schijven et al., 1999 - see above). Cells A1:L15 contain data from laboratory tracer tests using Yucca Mountain alluvium. Sources of these data are listed at the right of each data set. Cells A18:I34 contain the data from Schijven et al. (1999). Cells A36:I40 contain data from the cross-hole tracer test conducted in saturated alluvium at Nye County Site 22 (with the data source listed in columns H and I). Cells N1:P39 list the retardation factors (and their logarithms) and associated cumulative probabilities of all the data in ascending order. Cells Q1:T39 list the filtration rate constants (and their logarithms) and associated cumulative probabilities (and their logarithms) of all the data in ascending order. The data for the "truncated retardation factor cumulative distribution function are provided in Cells V2:X39, and the data for The field estimates of rate constants or retardation factors from the cross-hole tracer testing are given twice the probability weighting as the laboratory estimates and the estimates from Schijven et al. (1999). There are 4 plots in the "Volcanics Data" worksheet. The plot in columns B through K and rows 42 through 67 shows the filtration rate constant (hr^{-1}) vs. travel time (hrs). The plot directly below that plot shows the log of cumulative probability vs. log filtration rate constant (hr^{-1}). The plot in columns N through X shows cumulative probability vs. retardation factor for the "raw data", "truncated data", and "TSPA data", respectively. Finally, the plot in columns Z through AK shows cumulative probability vs. retardation factor for just the "truncated data." All plots except for the one in columns N through X appear in this ERD.

Worksheet "Combined Rates" – Contains the filtration rate constant data for both the volcanics and alluvium and provides a cumulative probability distribution for these data. Column A contains all the filtration rate constants in ascending order. Column B contains the cumulative probabilities associated with the rate constants. The NTS field data are given twice the probability weighting as the laboratory estimates and the estimates from Schijven et al. (1999). Columns C and D contain the logarithm of the values in columns A and B, respectively. The plot shows the log of cumulative probability vs. log filtration rate constant (hr^{-1}).

Worksheet "Fractions R=1" – Columns A and B contain tabulated values of times in years (assumed to be travel times) and critical filtration rate constants in hrs^{-1} (k_{fCrit}, which is just the inverse of the travel time with appropriate conversion factors applied) for the volcanics, alluvium, and combined volcanics and alluvium. Column C contains cumulative probabilities that are calculated as EXP(-1) times the cumulative probability associated with the value of k_{fCrit} from column B. The cumulative probability associated with k_{fCrit} is calculated (using the formula in column C) from the linear regression of log cumulative probability vs. log rate constant in one of the three previous worksheets (for volcanics, alluvium, and combined, respectively). Column D contains the log of the travel time in years (log of the value in column A). The two upper plots show the values in column C vs. the values in column A as the lines on the plots (for volcanics and alluvium, respectively). The lower plot shows column C vs. column A for volcanics, alluvium, and for the combined data (this plot appears in the ERD). The entries in the columns to the right of each plot contain exponential "fits" to the lines in the plots (where the fitting is done manually using the values immediately above the cells containing "Log yrs" and "Years" as the fitting parameters). The best-fitting equation is provided directly below the cells containing the text "Exponential Fit" above each table of values. The "fitted data points" are shown as blue diamonds on the plots. Note that the exponential fits were originally intended to be used as a way of easily calculating a fast fraction for any given travel time in the volcanics, the alluvium, or the combined system, but this approach was ultimately not implemented.

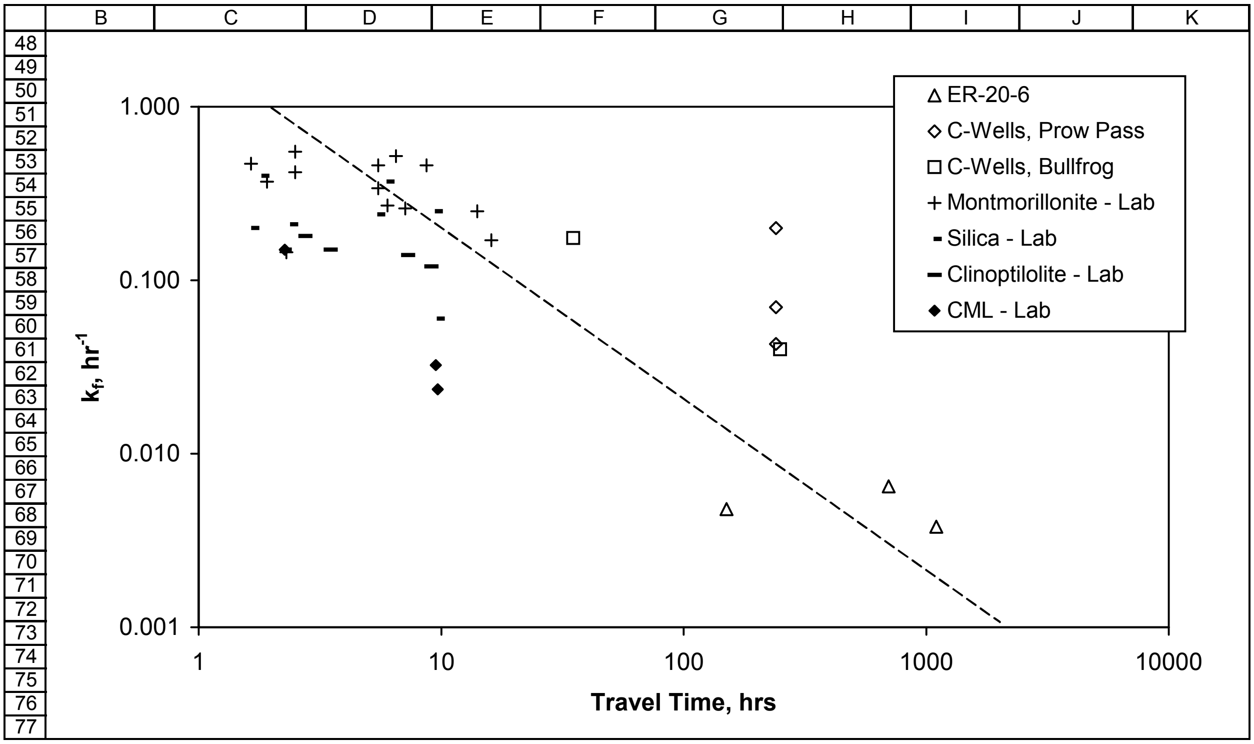
Assumptions, Limitations, and Caveats associated with Data Package:

- The density of the solutions collected from the columns was assumed to be 1 g/mL.
- Based on a limited number of liquid scintillation measurements of filtered column effluent samples, it was apparent that essentially all of the Pu-239 that eluted through the columns was sorbed to natural colloids (the concentration of Pu-239 in the filtered samples was at background levels – even for samples collected adjacent to unfiltered samples in which a significant concentration of Pu-239 was measured).
- Although the colloids collected from well NC-EWDP-19D1 zone #1 groundwater are called "natural", it is possible that they consisted largely of small particles of bentonite clay that was used as drilling mud when the well was drilled. The ultimate origin of the colloids was never definitively determined.
- Although the Pu-239 stock solution was verified to be predominantly Pu(V) before and after the experiments, it is possible that a significant fraction of the Pu that sorbed to the colloids was reduced to Pu(IV) on the surface of the colloids.

"Volcanics Data" Worksheet:

	A	B	C	D	E	F	G
1	Filtration Rate Constants and Retardation Factors						
2	Field Data (all microspheres)					Parameter	
3	Time, hr	Filt Rate, hr-1	Det. Rate, hr-1	Ret Fac.	Site	Est. Source DTN:	
4	35	0.175			C-Wells BF	LA0303PR831231.003	
5	250	0.04			C-Wells BF	LA0303PR831231.003	
6	150	0.0048	0.000228571	22	BULLION	LA0303PR831352.002	
7	700	0.0065		N/A	BULLION	LA0303PR831352.002	
8	1100	0.0038		N/A	BULLION	LA0303PR831352.002	
9	240	0.043	0.000154122	280	C-Wells PP	LA0303PR831231.003	
10	240	0.07	0.000250896	280	C-Wells PP	LA0303PR831231.003	
11	240	0.2			C-Wells PP	LA0303PR831231.003	
12							
13	Lab Data						
14							Parameter
15	Time, hr	Filt Rate Constant	Rev. Filt Rate Cons	Ret. Factor	Colloid Type		Est. Source DTN:
16	6	0.27	0.014210526	20	Cheto Montmorillinite		LA0403PR831352.001
17	16.1	0.17	0.004358974	40	Cheto Montmorillinite		LA0403PR831352.001
18	5.5	0.34	0.017894737	20	Cheto Montmorillinite		LA0403PR831352.001
19	14.1	0.25	0.004237288	60	Cheto Montmorillinite		LA0403PR831352.001
20	1.83	0.4	0.030769231	14	Silica		LA0403PR831352.001
21	6	0.37	0.164444444	3.25	Silica		LA0403PR831352.001
22	1.66	0.2	0.033333333	7	Silica		LA0403PR831352.001
23	5.5	0.24	0.16	2.5	Silica		LA0403PR831352.001
24	2.26	0.15	0.1	2.5	Silica		LA0403PR831352.001
25	9.67	0.06	0.005454545	12	Silica		LA0403PR831352.001
26	9.5	0.25	0.006410256	40	Silica		LA0403PR831352.001
27	2.4	0.21	0.007241379	30	Silica		LA0403PR831352.001
28	1.91	0.37	0.008222222	46	Otay Montmorillinite - 1		LA0403PR831352.001
29	6.5	0.52	0.022608696	24	Otay Montmorillinite - 1		LA0403PR831352.001
30	1.64	0.47	0.009038462	53	Otay Montmorillinite - 1		LA0403PR831352.001
31	5.5	0.46	0.009387755	50	Otay Montmorillinite - 1		LA0403PR831352.001
32	2.75	0.18	0.013846154	14	Clinoptilolite		LA0403PR831352.001
33	7.3	0.14	0.002372881	60	Clinoptilolite		LA0403PR831352.001
34	3.5	0.15	0.016666667	10	Clinoptilolite		LA0403PR831352.001
35	9.1	0.12	0.003076923	40	Clinoptilolite		LA0403PR831352.001
36	2.5	0.55	0.017741935	32	Otay Montmorillinite - 2		LA0403PR831352.001
37	7.1	0.26	0.000635697	410	Otay Montmorillinite - 2		LA0403PR831352.001
38	2.5	0.42	0.021	21	Otay Montmorillinite - 2		LA0403PR831352.001
39	8.7	0.46	0.000767947	600	Otay Montmorillinite - 2		LA0403PR831352.001
40	2.3	0.145	0.058	3.5	Otay Montmorillinite - 1		LA0403PR831352.001
41	2.26	0.15	0.15	2	CML Microsphere		LA0403PR831352.001
42	9.67	0.0235	0.000479592	50	CML Microsphere		LA0403PR831352.001
43	9.5	0.0325	0.0040625	9	CML Microsphere		LA0403PR831352.001
44	0.55	0		1	CML Microsphere		LA0403PR831352.001
45	0.55	0		1	Silica		LA0403PR831352.001
46	Notes:						
47		not used (Res. Time too short)					

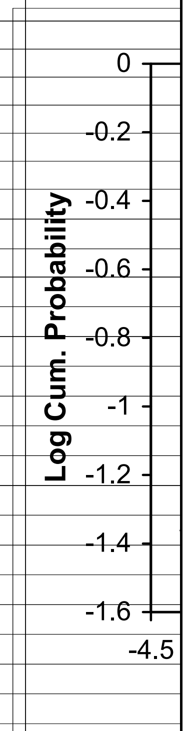
"Volcanics Data" Worksheet:



	I	J	K	L	M	N	O	P
1								
2	C-wells Individual Peaks or Microspheres				Sorted Ret. Factors		Parameter	
3	Time, hr	kf	kr	R	R	Mass Frac.	Est. Source DTN:	
4	35	0.175	0.000219	800.086758	1.162	0.03478261	LA0303PR831231.003	
5	35	0.175	1.08	1.16203704	1.19	0.11666667	LA0303PR831231.003	
6	250	0.04	0.000201	200.004975	6.3	0.18333333	LA0303PR831231.003	
7	250	0.04	0.211	1.18957346	200	0.7	LA0303PR831231.003	
8	250	0.04	0.00755	6.29801325	280	1	LA0303PR831231.003	
9	240	0.043	0.000154	280.220779	800	0.96521739	LA0303PR831231.003	
10	240	0.07	0.000251	279.884462			LA0303PR831231.003	
11	240	0.2	0.0002	Not rec'd			LA0303PR831231.003	
12					Sum =	3		

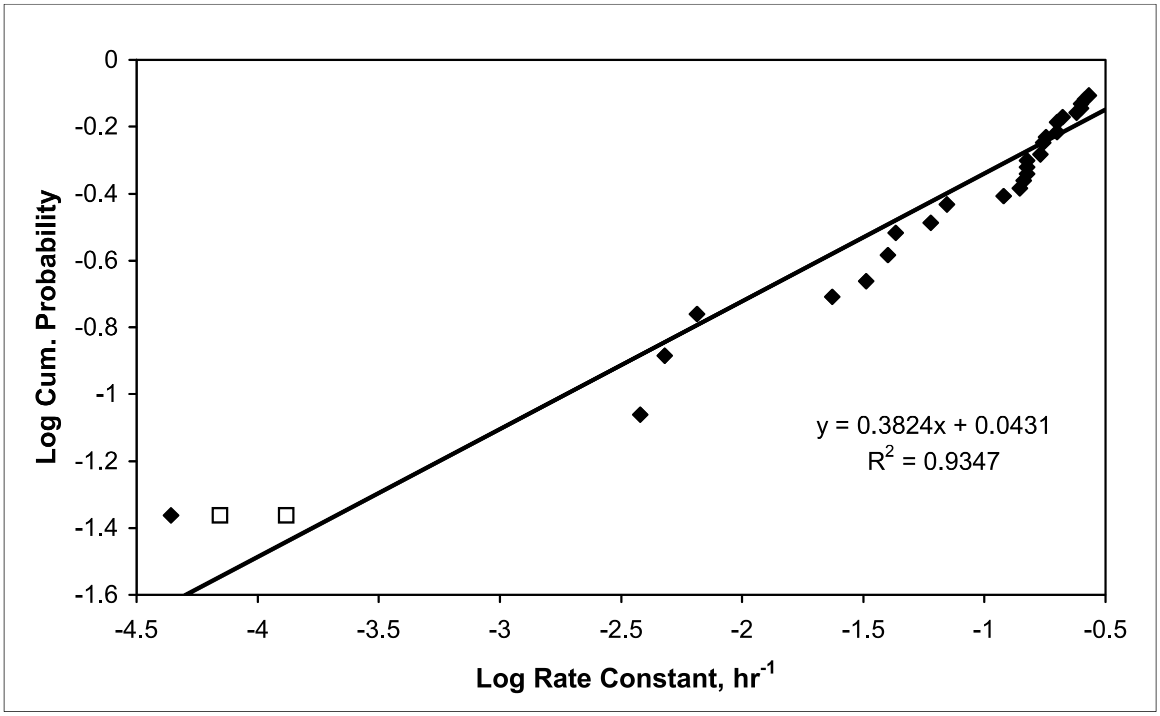
"Volcanics Data" Worksheet:

	R	S	T	U	V	W
1	All Data - Filtration Rate Constants			Field Data shown in Red and Weighted 2X		
2	Filt Rate Constant	Cum. Prob.	Log kf	Log (Cum.Prob)		
3		0.04347826				
4		0.02173913				
5	0.0000438	0.04347826	-4.3585259	-1.361727836		
6	0.0038	0.08695652	-2.4202164	-1.06069784		
7	0.0048	0.13043478	-2.3187588	-0.884606581		
8	0.0065	0.17391304	-2.1870866	-0.759667845		
9	0.0235	0.19565217	-1.6289321	-0.708515322		
10	0.0325	0.2173913	-1.4881166	-0.662757832		
11	0.04	0.26086957	-1.39794	-0.583576586		
12	0.043	0.30434783	-1.3665315	-0.516629796		
13	0.06	0.32608696	-1.2218487	-0.486666573		
14	0.07	0.36956522	-1.154902	-0.43230891		
15	0.12	0.39130435	-0.9208188	-0.407485327		
16	0.14	0.41304348	-0.853872	-0.384004231		
17	0.145	0.43478261	-0.838632	-0.361727836		
18	0.15	0.45652174	-0.8239087	-0.340538537		
19	0.15	0.47826087	-0.8239087	-0.320335151		
20	0.15	0.5	-0.8239087	-0.301029996		
21	0.17	0.52173913	-0.7695511	-0.28254659		
22	0.175	0.56521739	-0.756962	-0.247784484		
23	0.18	0.58695652	-0.7447275	-0.231394068		
24	0.2	0.60869565	-0.69897	-0.2155998		
25	0.2	0.65217391	-0.69897	-0.185636577		
26	0.21	0.67391304	-0.6777807	-0.171396138		
27	0.24	0.69565217	-0.6197888	-0.157607853		
28	0.25	0.7173913	-0.60206	-0.144243892		
29	0.25	0.73913043	-0.60206	-0.131278915		
30	0.26	0.76086957	-0.5850267	-0.118689787		
31	0.27	0.7826087	-0.5686362	-0.106455331		
32	0.34	0.80434783	-0.4685211	-0.094556108		
33	0.37	0.82608696	-0.4317983	-0.082974235		
34	0.37	0.84782609	-0.4317983	-0.071693225		
35	0.4	0.86956522	-0.39794	-0.06069784		
36	0.42	0.89130435	-0.3767507	-0.049973975		
37	0.46	0.91304348	-0.3372422	-0.039508541		Sensitivity to the
38	0.46	0.93478261	-0.3372422	-0.029289376		C/Co
39	0.47	0.95652174	-0.3279021	-0.019305155		1.00E-05
40	0.52	0.97826087	-0.2839967	-0.009545318		1.00E-05
41	0.55	1	-0.2596373	-2.41082E-16		1.00E-08



"Volcanics Data" Worksheet:

	W	X	Y	Z	AA	AB	AC	AD	AE
4									

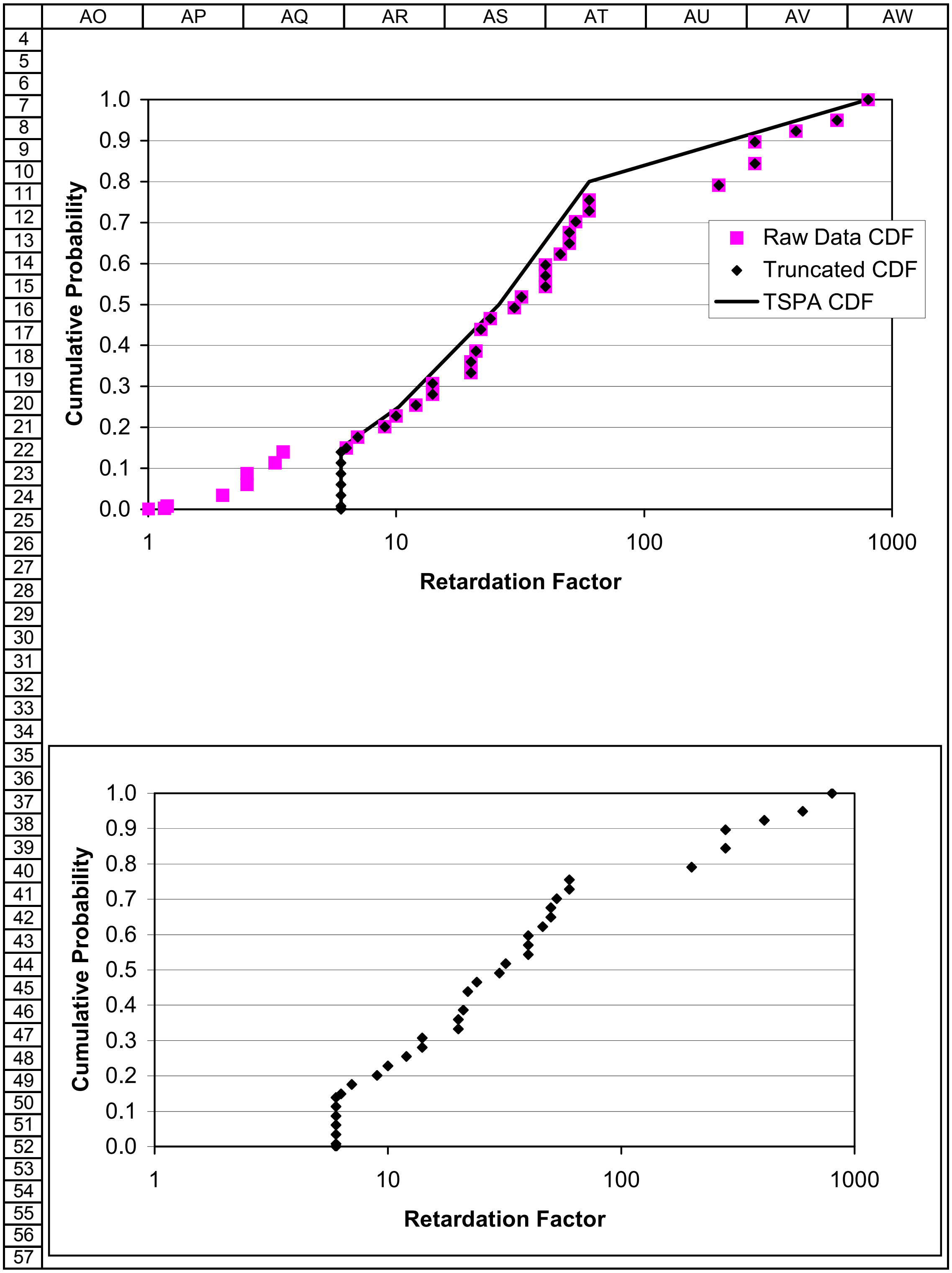


	W	X	Y	Z	AA	AB	AC	AD	AE
37	Sensitivity to the ER-20-5 assumed travel times and C/Co values:								
38	C/Co	Time, yrs	kf, 1/hr	Log kf (1/hr)	Prob.				
39	1.00E-05	30	4.3779E-05	-4.358737					
40	1.00E-05	10	0.00013134	-3.8816158	-1.3617278				
41	1.00E-08	30	7.0046E-05	-4.154617	-1.3617278				

"Volcanics Data" Worksheet:

	AF	AG	AH	AI	AJ	AK	AL	AM
1	All Data - Retardation Factors			Truncated Data CDF			TSPA CDF	
2	Ret. Fac	Cum. Prob.						
3		0.05263		Ret. Fac	Cum. Prob.		Ret. Fac	Cum. Prob.
4		0.02632						
5	1	1.00E-05		6	1.00E-05		6	0
6	1.162	1.84E-03		6	1.84E-03		6	0.15
7	1.19	7.98E-03		6	7.98E-03		10.23	0.25
8	2	3.43E-02		6	3.43E-02		26	0.5
9	2.5	6.06E-02		6	6.06E-02		59.98	0.8
10	2.5	8.69E-02		6	8.69E-02		800	1
11	3.25	1.13E-01		6	1.13E-01			
12	3.5	1.40E-01		6	1.40E-01			
13	6.3	1.49E-01		6.3	1.49E-01			
14	7	1.76E-01		7	1.76E-01			
15	9	2.02E-01		9	2.02E-01			
16	10	2.28E-01		10	2.28E-01			
17	12	2.54E-01		12	2.54E-01			
18	14	2.81E-01		14	2.81E-01			
19	14	3.07E-01		14	3.07E-01			
20	20	3.33E-01		20	3.33E-01			
21	20	3.60E-01		20	3.60E-01			
22	21	3.86E-01		21	3.86E-01			
23	22	4.39E-01		22	4.39E-01			
24	24	4.65E-01		24	4.65E-01			
25	30	4.91E-01		30	4.91E-01			
26	32	5.18E-01		32	5.18E-01			
27	40	5.44E-01		40	5.44E-01			
28	40	5.70E-01		40	5.70E-01			
29	40	5.97E-01		40	5.97E-01			
30	46	6.23E-01		46	6.23E-01			
31	50	6.49E-01		50	6.49E-01			
32	50	6.76E-01		50	6.76E-01			
33	53	7.02E-01		53	7.02E-01			
34	60	7.28E-01		60	7.28E-01			
35	60	7.54E-01		60	7.54E-01			
36	200	7.91E-01		200	7.91E-01			
37	280	8.44E-01		280	8.44E-01			
38	280	8.97E-01		280	0.89658			
39	410	9.23E-01		410	9.23E-01			
40	600	9.49E-01		600	9.49E-01			
41	800	1.00E+00		800	1.00E+00			

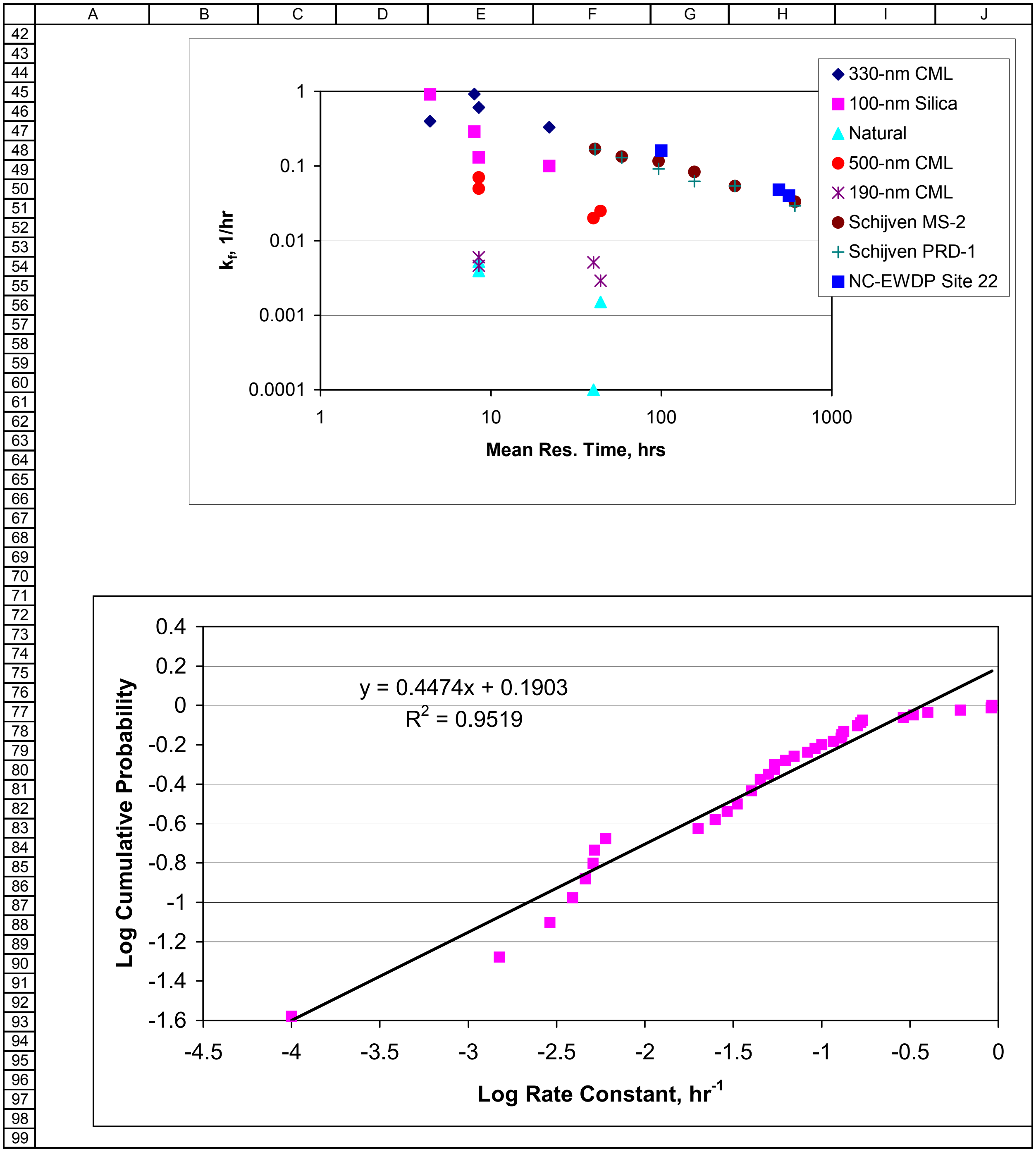
"Volcanics Data" Worksheet:



"Alluvium Data" Worksheet:

	A	B	C	D	E	F	G	H	I	J	K	L
1	1st set of Alluvium Column Experiments (100-nm silica and 330-nm CML microspheres)											
2		CML Spheres			Silica							
3	Res. Time, hrs	kf, 1/hr	kr, 1/hr	R	kf, 1/hr	kr, 1/hr	R	Parameter Est. Source DTN:				
4	4.4	0.4	0.001606	250	0.91	0.0364	26	LA0303PR831361.001				
5	8	0.92	0.006619	140	0.29	0.015263158	20	LA0303PR831361.001				
6	22	0.33	0.006111	55	0.1	0.007692308	14	LA0303PR831361.001				
7	8.5	0.61	0.018485	34	0.13	0.008666667	16	LA0303PR831361.001				
8												
9	2nd set of Alluvium Column Experiments ("natural" colloids, 500-nm CML spheres, 190 nm CML spheres)											
10		Natural Colloids			500-nm CML			190-nm CML				
11	Res. Time, hrs	kf, 1/hr	kr, 1/hr	R	kf, 1/hr	kr, 1/hr	R	kf, 1/hr	kr, 1/hr	R	Parameter Est. Source DTN	
12	8.5	0.0052	0.007429	1.7	0.05	0.005	11	0.006	0.012	1.5	LA0303PR831361.001	
13	40	0.0001		1	0.02	0.002857143	8	0.0051	0.0102	1.5	LA0303PR831361.001	
14	8.5	0.0039	0.0078	1.5	0.07	0.02	4.5	0.0046	0.0092	1.5	LA0303PR831361.001	
15	44	0.0015	0.003	1.5	0.025	0.000735294	35	0.0029	0.0058	1.5	LA0303PR831361.001	
16												
17												
18	Data from Schijven et al. - Field Data (Bacteriophages) - Parameter Estimations all come from this source											
19	MS2											
20	Well ID	x,m	v, m/d	Res Time, hr	kf, 1/day	kr, 1/day	kf, 1/hr	kr, 1/hr	R			
21	W1	2.4	1.41	40.8510638	4.1	0.00087	0.170833	0.00003625	4712.643678			
22	W2	3.8	1.56	58.4615385	3.2	0.0016	0.133333	6.66667E-05	2000			
23	W3	6.4	1.59	96.6037736	2.8	0.0026	0.116667	0.000108333	1076.923077			
24	W4	10.2	1.57	155.923567	2	0.0018	0.083333	0.000075	1111.111111			
25	W5	17.1	1.52	270	1.3	0.00052	0.054167	2.16667E-05	2500			
26	W6	30.1	1.19	607.058824	0.8	0.003	0.033333	0.000125	266.6666667			
27	PRD1											
28	Well ID	x,m	v, m/d	Res Time, hr	kf, 1/day	kr, 1/day	kf, 1/hr	kr, 1/hr	R			
29	W1	2.4	1.41	40.8510638	4	0.00077	0.166667	3.20833E-05	5194.805195			
30	W2	3.8	1.56	58.4615385	3.1	0.0011	0.129167	4.58333E-05	2818.181818			
31	W3	6.4	1.59	96.6037736	2.2	0.0018	0.091667	0.000075	1222.222222			
32	W4	10.2	1.57	155.923567	1.5	0.0025	0.0625	0.000104167	600			
33	W5	17.1	1.52	270	1.3	0.0021	0.054167	0.0000875	619.047619			
34	W6	30.1	1.19	607.058824	0.7	0.0034	0.029167	0.000141667	205.8823529			
35												
36	YM Alluvium-Specific Data											
37	Well ID	x,m	mass frac	Res Time, hr	kf, 1/hr	kr, 1/hr	R	Parameter Est. Source DTN:				
38	22S	18	0.05	100	0.16	0.001073826	150	LA0701PR150304.002				
39	22S	18	0.58	490	0.048	0.000322148	150	LA0701PR150304.002				
40	22S	18	0.33	560	0.04	0.000268456	150	LA0701PR150304.002				

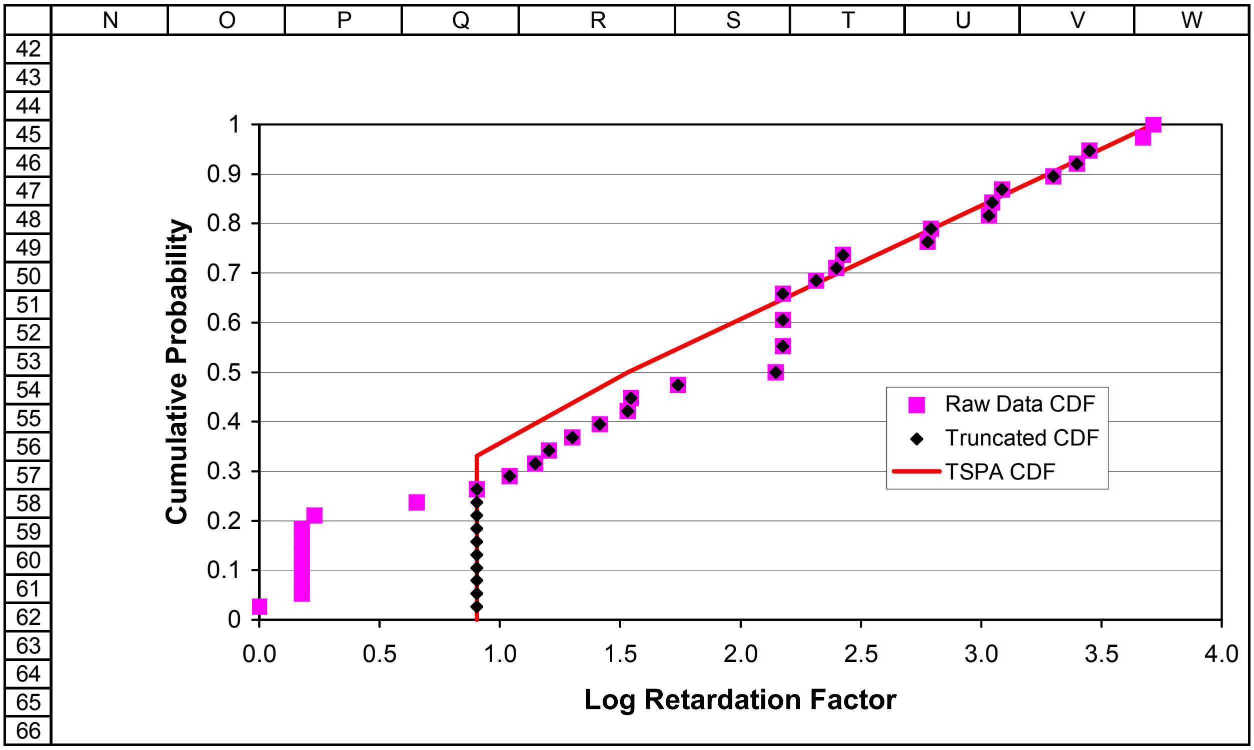
“Alluvium Data” Worksheet:



"Alluvium Data" Worksheet:

	N	O	P	Q	R	S	T
1	Field Data shown in Red and Weighted 2X						
2	"Raw" Data CDFs						
3			Prob. R			Prob kf	Log P(kf)
4	R	Log(R)	0.026316	kf	Log(kf)	0.026316	
5	1	0	0.026316	0.0001	-4	0.026316	-1.57978
6	1.5	0.176091	0.052632	0.0015	-2.823908741	0.052632	-1.27875
7	1.5	0.176091	0.078947	0.0029	-2.537602002	0.078947	-1.10266
8	1.5	0.176091	0.105263	0.0039	-2.408935393	0.105263	-0.97772
9	1.5	0.176091	0.131579	0.0046	-2.337242168	0.131579	-0.88081
10	1.5	0.176091	0.157895	0.0051	-2.292429824	0.157895	-0.80163
11	1.5	0.176091	0.184211	0.0052	-2.283996656	0.184211	-0.73469
12	1.7	0.230449	0.210526	0.006	-2.22184875	0.210526	-0.67669
13	4.5	0.653213	0.236842	0.02	-1.698970004	0.236842	-0.62554
14	8	0.90309	0.263158	0.025	-1.602059991	0.263158	-0.57978
15	11	1.041393	0.289474	0.029167	-1.535113202	0.289474	-0.53839
16	14	1.146128	0.315789	0.033333	-1.477121255	0.315789	-0.5006
17	16	1.20412	0.342105	0.04	-1.397940009	0.368421	-0.43366
18	20	1.30103	0.368421	0.045	-1.346787486	0.421053	-0.37566
19	26	1.414973	0.394737	0.05	-1.301029996	0.447368	-0.34933
20	34	1.531479	0.421053	0.054167	-1.266267889	0.473684	-0.32451
21	35	1.544068	0.447368	0.054167	-1.266267889	0.5	-0.30103
22	55	1.740363	0.473684	0.0625	-1.204119983	0.526316	-0.27875
23	140	2.146128	0.5	0.07	-1.15490196	0.552632	-0.25756
24	150	2.176091	0.552632	0.083333	-1.079181246	0.578947	-0.23736
25	150	2.176091	0.605263	0.091667	-1.037788561	0.605263	-0.21806
26	150	2.176091	0.657895	0.1	-1	0.631579	-0.19957
27	205.8824	2.313619	0.684211	0.116667	-0.93305321	0.657895	-0.18184
28	250	2.39794	0.710526	0.129167	-0.888849548	0.684211	-0.16481
29	266.6667	2.425969	0.736842	0.13	-0.886056648	0.710526	-0.14842
30	600	2.778151	0.763158	0.133333	-0.875061263	0.736842	-0.13263
31	619.0476	2.791724	0.789474	0.16	-0.795880017	0.789474	-0.10266
32	1076.923	3.032185	0.815789	0.166667	-0.77815125	0.815789	-0.08842
33	1111.111	3.045757	0.842105	0.170833	-0.767427385	0.842105	-0.07463
34	1222.222	3.08715	0.868421	0.29	-0.537602002	0.868421	-0.06127
35	2000	3.30103	0.894737	0.33	-0.48148606	0.894737	-0.0483
36	2500	3.39794	0.921053	0.4	-0.397940009	0.921053	-0.03572
37	2818.182	3.449969	0.947368	0.61	-0.214670165	0.947368	-0.02348
38	4712.644	3.673265	0.973684	0.91	-0.040958608	0.973684	-0.01158
39	5194.805	3.715569	1	0.92	-0.036212173	1	-2.9E-16

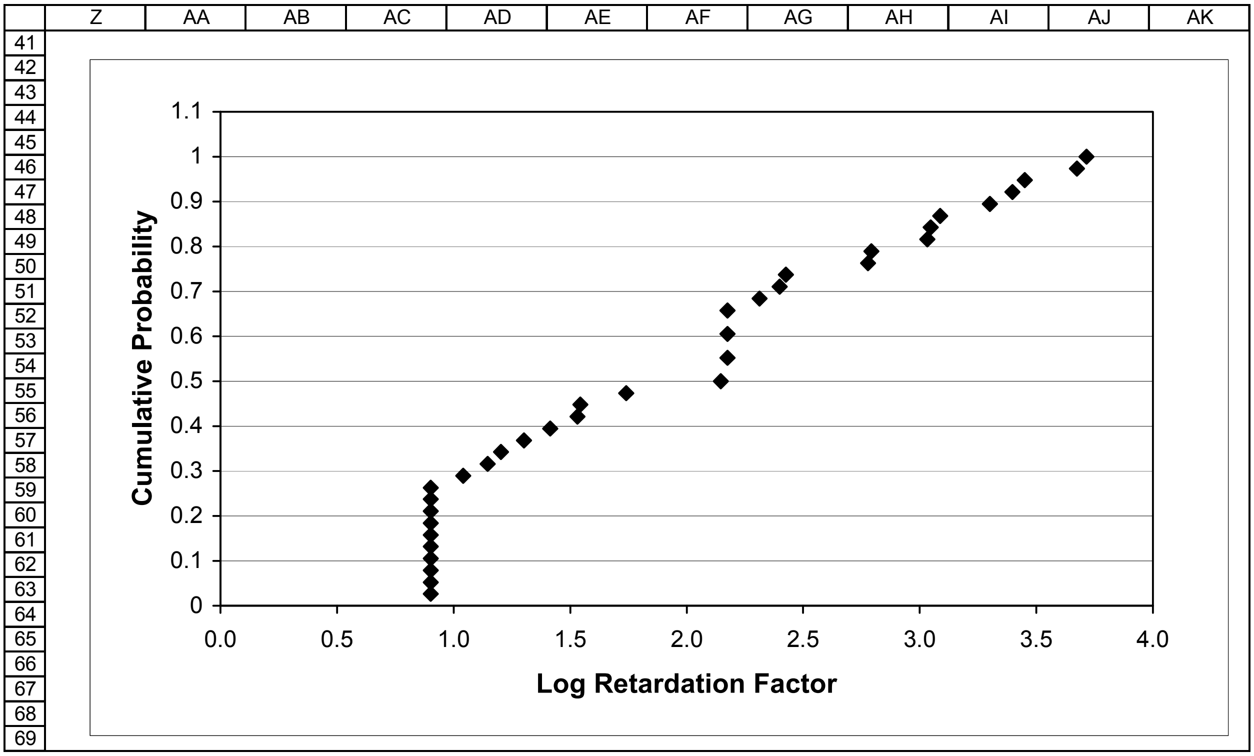
"Alluvium Data" Worksheet:



"Alluvium Data" Worksheet:

	V	W	X	Y	Z	AA	AB
1							
2	Truncated Data CDF				TSPA CDF		
3			Prob.				
4	R	Log(R)	0.026316		R	Log(R)	Prob.
5	8	0.90309	0.026316		8	0.90309	0
6	8	0.90309	0.052632		8	0.90309	0.331
7	8	0.90309	0.078947		33.96	1.530968	0.5
8	8	0.90309	0.105263		5188	3.715	1
9	8	0.90309	0.131579				
10	8	0.90309	0.157895				
11	8	0.90309	0.184211				
12	8	0.90309	0.210526				
13	8	0.90309	0.236842				
14	8	0.90309	0.263158				
15	11	1.041393	0.289474				
16	14	1.146128	0.315789				
17	16	1.20412	0.342105				
18	20	1.30103	0.368421				
19	26	1.414973	0.394737				
20	34	1.531479	0.421053				
21	35	1.544068	0.447368				
22	55	1.740363	0.473684				
23	140	2.146128	0.5				
24	150	2.176091	0.552632				
25	150	2.176091	0.605263				
26	150	2.176091	0.657895				
27	205.8824	2.313619	0.684211				
28	250	2.39794	0.710526				
29	266.6667	2.425969	0.736842				
30	600	2.778151	0.763158				
31	619.0476	2.791724	0.789474				
32	1076.923	3.032185	0.815789				
33	1111.111	3.045757	0.842105				
34	1222.222	3.08715	0.868421				
35	2000	3.30103	0.894737				
36	2500	3.39794	0.921053				
37	2818.182	3.449969	0.947368				
38	4712.644	3.673265	0.973684				
39	5194.805	3.715569	1				

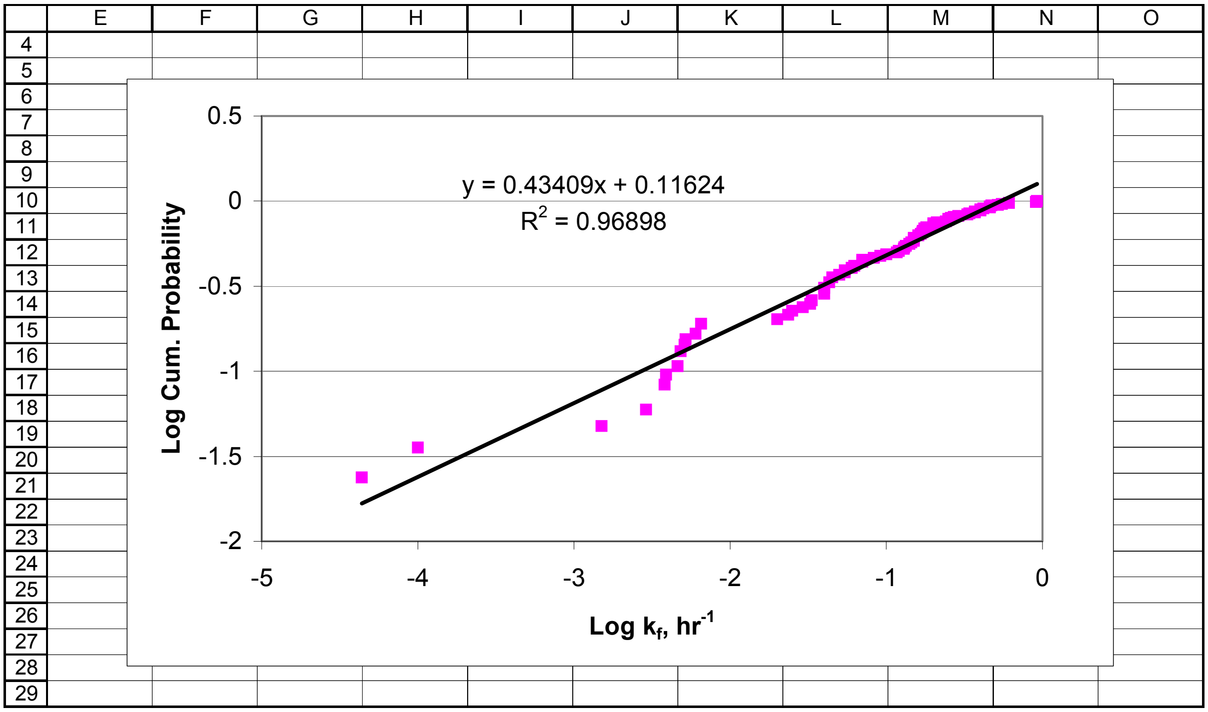
"Alluvium Data" Worksheet:



"Combined Rates" Worksheet:

	A	B	C	D
1	All Data -	Volcanics and Alluvium		
2		0.0119048		
3		0.0238095		
4	kf	Prob.	Log(kf)	Log(Prob)
5	0.0000438	0.02381	-4.358526	-1.62325
6	0.0001	0.035714	-4	-1.44716
7	0.0015	0.047619	-2.823909	-1.32222
8	0.0029	0.059524	-2.537602	-1.22531
9	0.0038	0.083333	-2.420216	-1.07918
10	0.0039	0.095238	-2.408935	-1.02119
11	0.0046	0.107143	-2.337242	-0.97004
12	0.0048	0.130952	-2.318759	-0.88289
13	0.0051	0.142857	-2.29243	-0.8451
14	0.0052	0.154762	-2.283997	-0.81034
15	0.006	0.166667	-2.221849	-0.77815
16	0.0065	0.190476	-2.187087	-0.72016
17	0.02	0.202381	-1.69897	-0.69383
18	0.0235	0.214286	-1.628932	-0.66901
19	0.025	0.22619	-1.60206	-0.64553
20	0.029167	0.238095	-1.535113	-0.62325
21	0.0325	0.25	-1.488117	-0.60206
22	0.033333	0.261905	-1.477121	-0.58186
23	0.04	0.285714	-1.39794	-0.54407
24	0.04	0.309524	-1.39794	-0.50931
25	0.043	0.333333	-1.366532	-0.47712
26	0.045	0.357143	-1.346787	-0.44716
27	0.05	0.369048	-1.30103	-0.43292
28	0.054167	0.380952	-1.266268	-0.41913
29	0.054167	0.392857	-1.266268	-0.40577
30	0.06	0.404762	-1.221849	-0.3928
31	0.0625	0.416667	-1.20412	-0.38021
32	0.07	0.440476	-1.154902	-0.35608
33	0.07	0.452381	-1.154902	-0.3445
34	0.083333	0.464286	-1.079181	-0.33321
35	0.091667	0.47619	-1.037789	-0.32222
36	0.1	0.488095	-1	-0.3115
37	0.116667	0.5	-0.933053	-0.30103
38	0.12	0.511905	-0.920819	-0.29081
39	0.129167	0.52381	-0.88885	-0.28083
40	0.13	0.535714	-0.886057	-0.27107
41	0.133333	0.547619	-0.875061	-0.26152
42	0.14	0.559524	-0.853872	-0.25218
43	0.145	0.571429	-0.838632	-0.24304
44	0.15	0.583333	-0.823909	-0.23408
45	0.15	0.595238	-0.823909	-0.22531
46	0.15	0.607143	-0.823909	-0.21671
47	0.16	0.630952	-0.79588	-0.2
48	0.166667	0.642857	-0.778151	-0.19189
49	0.17	0.654762	-0.769551	-0.18392
50	0.170833	0.666667	-0.767427	-0.17609
51	0.175	0.690476	-0.756962	-0.16085
52	0.18	0.702381	-0.744727	-0.15343
53	0.2	0.714286	-0.69897	-0.14613
54	0.2	0.738095	-0.69897	-0.13189
55	0.21	0.75	-0.677781	-0.12494
56	0.24	0.761905	-0.619789	-0.1181
57	0.25	0.77381	-0.60206	-0.11137
58	0.25	0.785714	-0.60206	-0.10474
59	0.26	0.797619	-0.585027	-0.0982
60	0.27	0.809524	-0.568636	-0.09177
61	0.29	0.821429	-0.537602	-0.08543
62	0.33	0.833333	-0.481486	-0.07918
63	0.34	0.845238	-0.468521	-0.07302
64	0.37	0.857143	-0.431798	-0.06695
65	0.37	0.869048	-0.431798	-0.06096
66	0.4	0.880952	-0.39794	-0.05505
67	0.4	0.892857	-0.39794	-0.04922
68	0.42	0.904762	-0.376751	-0.04347
69	0.46	0.916667	-0.337242	-0.03779
70	0.46	0.928571	-0.337242	-0.03218
71	0.47	0.940476	-0.327902	-0.02665
72	0.52	0.952381	-0.283997	-0.02119
73	0.55	0.964286	-0.259637	-0.01579

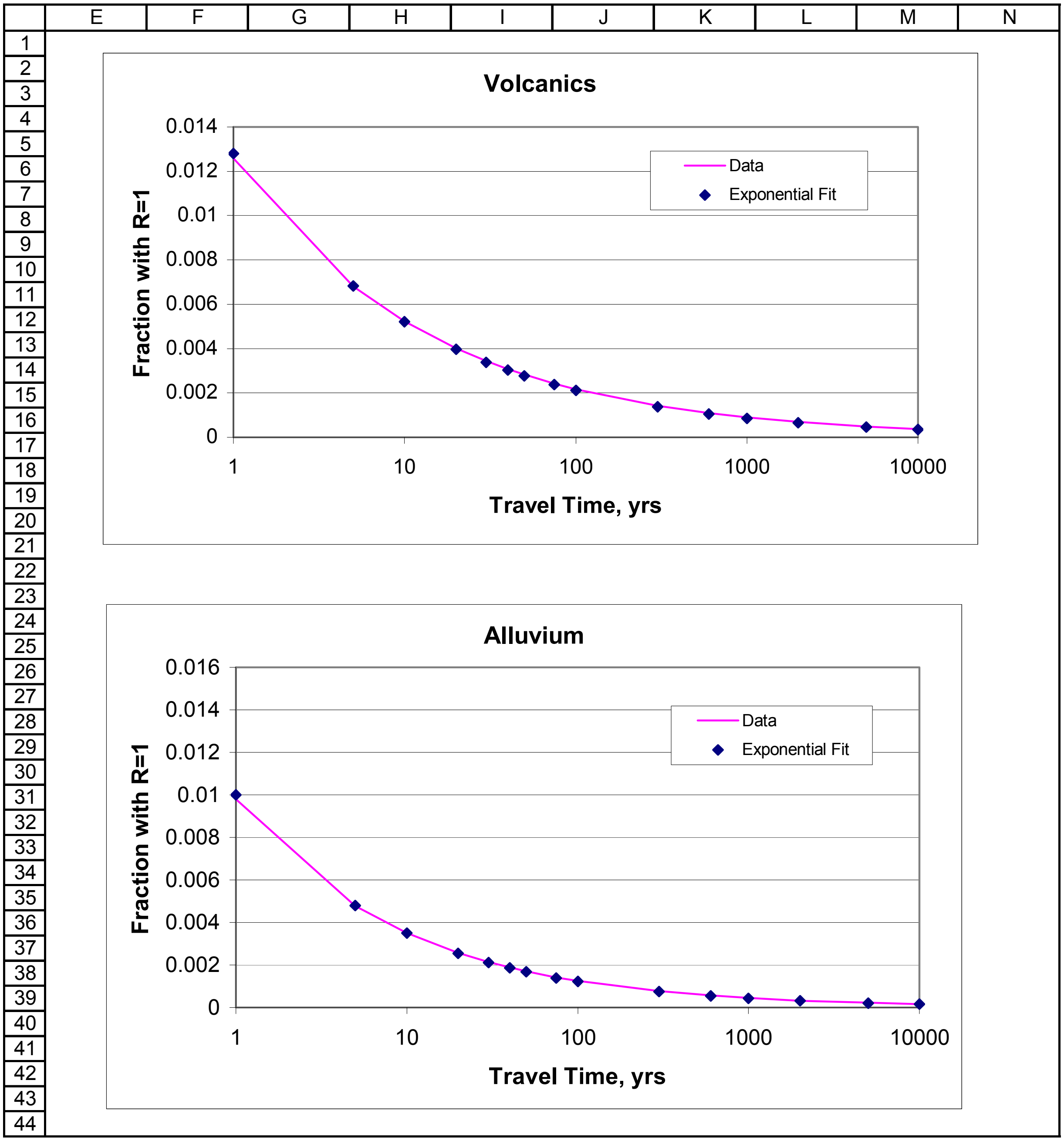
"Combined Rates" Worksheet:



"Fractions R=1" Worksheet:

	A	B	C	D
1				
2	Volcanics			
3	Years	kf Crit	Fast Frac	Log yrs
4	1	0.0001134	0.0125882	0
5	5	2.268E-05	0.0068022	0.69897
6	10	1.141E-05	0.0052297	1
7	20	5.704E-06	0.0040119	1.30103
8	30	3.803E-06	0.0034357	1.4771213
9	40	2.852E-06	0.0030777	1.60206
10	50	2.282E-06	0.002826	1.69897
11	75	1.521E-06	0.00242	1.8750613
12	100	1.141E-06	0.0021679	2
13	300	3.803E-07	0.0014242	2.4771213
14	600	1.901E-07	0.0010926	2.7781513
15	1000	1.141E-07	0.0008987	3
16	2000	5.704E-08	0.0006894	3.30103
17	5000	2.282E-08	0.0004856	3.69897
18	10000	1.141E-08	0.0003725	4
19				
20				
21				
22				
23				
24				
25	Alluvium		All Data	
26	Years	kf Crit	Fast Frac	Log yrs
27	1	0.0001134	0.0097912	0
28	5	2.268E-05	0.0047655	0.69897
29	10	1.134E-05	0.0034948	1
30	20	5.671E-06	0.002563	1.30103
31	30	3.781E-06	0.0021378	1.4771213
32	40	2.836E-06	0.0018796	1.60206
33	50	2.268E-06	0.001701	1.69897
34	75	1.512E-06	0.0014188	1.8750613
35	100	1.134E-06	0.0012474	2
36	300	3.781E-07	0.000763	2.4771213
37	600	1.89E-07	0.0005596	2.7781513
38	1000	1.134E-07	0.0004453	3
39	2000	5.671E-08	0.0003265	3.30103
40	5000	2.268E-08	0.0002167	3.69897
41	10000	1.134E-08	0.0001589	4
42				
43				
44				
45				
46				
47	Combined			
48	Years	kf Crit	Fast Frac	Log yrs
49	1	0.0001134	0.0093181	0
50	5	2.268E-05	0.0046335	0.69897
51	10	1.141E-05	0.0034382	1
52	20	5.704E-06	0.0025448	1.30103
53	30	3.803E-06	0.0021341	1.4771213
54	40	2.852E-06	0.0018835	1.60206
55	50	2.282E-06	0.0017097	1.69897
56	75	1.521E-06	0.0014337	1.8750613
57	100	1.141E-06	0.0012654	2
58	300	3.803E-07	0.0007855	2.4771213
59	600	1.901E-07	0.0005814	2.7781513
60	1000	1.141E-07	0.0004657	3
61	2000	5.704E-08	0.0003447	3.30103
62	5000	2.282E-08	0.0002316	3.69897
63	10000	1.141E-08	0.0001714	4

"Fractions R=1" Worksheet:



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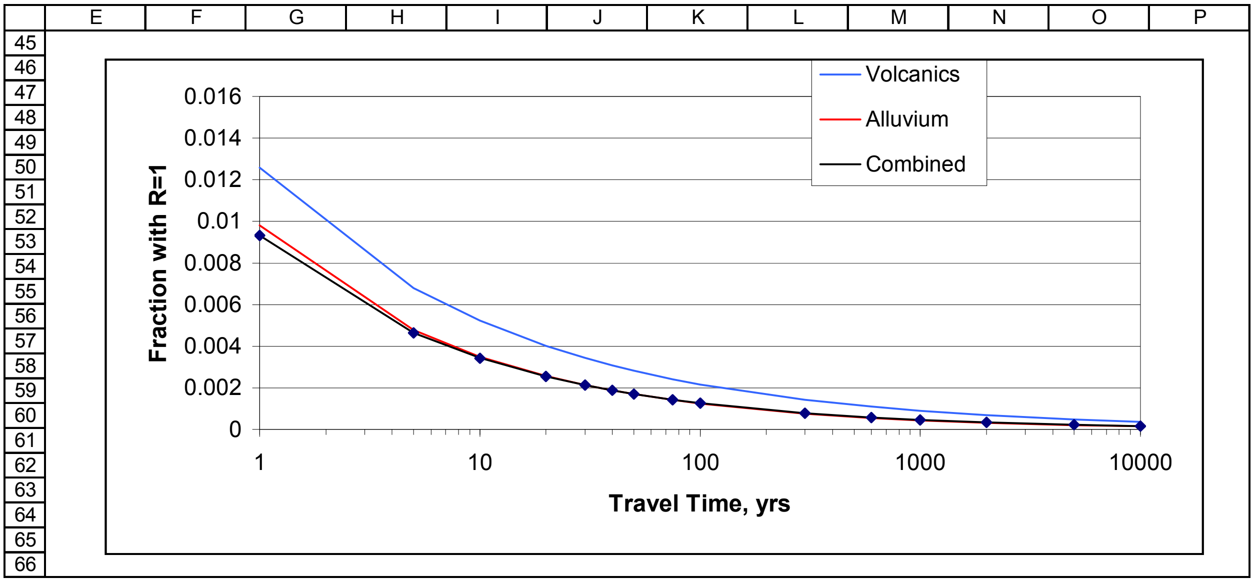


"Fractions R=1" Worksheet:

	O	P	Q	R	S
1	Exponential Fit				
2	0.0128*EXP(-0.9*(log yrs))				
3	0.9	0.0128			
4	Log yrs	Years	Fraction		
5	0	1	0.0128		
6	0.69897	5	0.006823		
7	1	10	0.005204		
8	1.30103	20	0.003969		
9	1.477121	30	0.003387		
10	1.60206	40	0.003027		
11	1.69897	50	0.002774		
12	1.875061	75	0.002368		
13	2	100	0.002116		
14	2.477121	300	0.001377		
15	2.778151	600	0.00105		
16	3	1000	0.00086		
17	3.30103	2000	0.000656		
18	3.69897	5000	0.000459		
19	4	10000	0.00035		
20					
21					
22				C/Co = EXP(-kT)	
23					
24	Exponential Fit				
25	0.01*EXP(-1.05*(log yrs))				
26	1.05	0.01			
27	Log yrs	Years	Fraction		
28	0	1	0.01		
29	0.69897	5	0.0048		
30	1	10	0.003499		
31	1.30103	20	0.002551		
32	1.477121	30	0.00212		
33	1.60206	40	0.00186		
34	1.69897	50	0.00168		
35	1.875061	75	0.001396		
36	2	100	0.001225		
37	2.477121	300	0.000742		
38	2.778151	600	0.000541		
39	3	1000	0.000429		
40	3.30103	2000	0.000312		
41	3.69897	5000	0.000206		
42	4	10000	0.00015		

"Fractions R=1" Worksheet:

	Q	R	S
46			
47	Exponential Fit		
48	0.00932*EXP(-(log yrs))		
49	1	0.00932	
50	Log yrs	Years	Fraction
51	0	1	9.32E-03
52	0.69897	5	4.63E-03
53	1	10	3.43E-03
54	1.30103	20	2.54E-03
55	1.477121	30	2.13E-03
56	1.60206	40	1.88E-03
57	1.69897	50	1.70E-03
58	1.875061	75	1.43E-03
59	2	100	1.26E-03
60	2.477121	300	7.83E-04
61	2.778151	600	5.79E-04
62	3	1000	4.64E-04
63	3.30103	2000	3.43E-04
64	3.69897	5000	2.31E-04
65	4	10000	1.71E-04

Attachment B

Changes to Relevant Pages from ANL-NBS-HS-000031 REV 02 ACN 01

(Callouts to sections not presented herein are to ANL-NBS-HS-000031 REV 02 ACN 01. For the ease of comparing to the parent report, the numbers of sections, figures, and tables are unchanged herein. The pages numbers are identified with the original pages number followed by "[a]". Yellow highlighting is used to call attention to changes relative to the parent report)

4. INPUTS

4.1 DIRECT INPUTS

Input information used in this analysis comes from several sources, summarized in Table 4-1 along with their data tracking numbers (DTNs). Note that all input in Table 4-1 is direct input. The data are fully appropriate for the discussion of colloid transport in the fractured volcanics and alluvium in this scientific analysis report. The qualification status of the input sources is provided in the Technical Data Management System. Uncertainty of the input parameters is discussed in Section 7.3.

Table 4-1. Direct Inputs [Note 7 rows of Table have been removed]

Data Description	Data Tracking Number	Data Used
Breakthrough curves of CML microspheres, silica colloids, and iodide in fractured cores from the NTS.	LA0301PR831352.001 [DIRS 162434]	S03034_001
RELAP computer code interpretations of solute and microsphere responses in the Bullfrog Tuff and Prow Pass Tuff tracer tests at the C-wells.	LA0303PR831231.003 [DIRS 163756]	C_Wells_Field_Test_Calcs
Calculations to determine detachment rate constant of microspheres in a singe-well tracer test in saturated alluvium.	LA0303PR831352.001 [DIRS 161138]	Calculations to Determine detachment rate constant of microspheres in a single- well tracer test in saturated alluvium
Model interpretations of ER-20-6 field tracer transport experiment	LA0303PR831352.002 [DIRS 163136] See Note 1 below for the justification of the use of UGTA/NTS data	Model Interpretations of ER-20-6 field tracer transport experiment
Model interpretations of NTS fractured core colloid and colloid-facilitated transport experiments	LA0403PR831352.001 [DIRS 171416] See Note 1 below for the justification of the use of UGTA/NTS data	Model interpretations of NTS fractured core colloid and colloid-facilitated transport experiments
RELAP computer code interpretations of colloid transport parameters in cross-hole tracer test at NC-EWDP Site 22	LA0701PR150304.002 [DIRS 185424]	RELAP V2.0 Model Interpretations of solute and colloid transport in field tracer test at NC-EWDP-Site 22
RELAP computer code interpretations of laboratory colloid transport parameters in alluvium.	LA0303PR831361.001 [DIRS 184301]	RELAP V2.0 Model Interpretations of solute and colloid transport in alluvium-packed column transport experiments
Breakthrough curves of CML microspheres, silica colloids, and bromide in alluvium-packed Column A, Run 1.	LA0206MH831361.001 [DIRS 162426]	S02152_001
Breakthrough curves of CML microspheres, silica colloids, and bromide in alluvium-packed Column B, Run 1.	LA0206MH831361.002 [DIRS 162427]	S02153_001

Table 4-1. Direct Inputs (Continued)

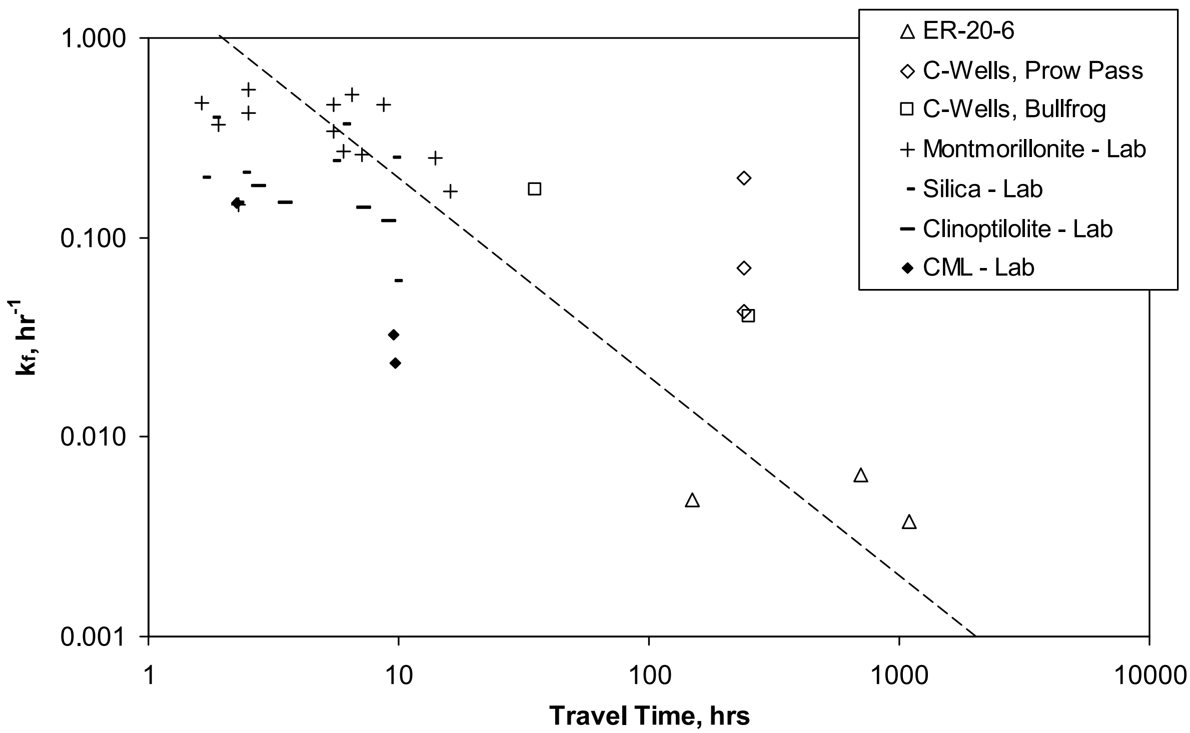
Data Description	Data Tracking Number	Data Used
Breakthrough curves of CML microspheres, silica colloids, and bromide in alluvium-packed Column A, Run 2.	LA0206MH831361.003 [DIRS 162428]	S02154_001
Breakthrough curves of CML microspheres, silica colloids, and bromide in alluvium-packed Column B, Run 2.	LA0206MH831361.004 [DIRS 162430]	S02155_001
Breakthrough curves of tritium, Pu, and natural colloids in two alluvium-packed columns.	LA0711PR150304.004 [DIRS 185425]	S07177_001
Field-scale attachment/detachment rates and retardation factors for colloids in alluvial material	Schijven et al. 1999 [DIRS 162423] See Note 2 below for the justification of the use of literature data	Rate constants and retardation factors obtained from model interpretations of colloid breakthrough curves.

NOTE 1: Justification for use of data obtained from outside sources (AP-SIII.9Q, *Scientific Analyses*): The UGTA/NTS data used in this report were obtained from outside sources. These data were obtained from the U.S. Department of Energy UGTA program, which has a quality assurance program in place. In addition, the researchers collecting the data are the same researchers conducting the Yucca Mountain colloid research (e.g., Paul Reimus, coauthor of this report). The data were collected at the same laboratory facilities as the Yucca Mountain data. Therefore, the reliability of the data source and the qualifications of personnel or organizations generating the data is sufficient. The data apply to this analysis because the UGTA program operates in close proximity to Yucca Mountain, making it a good analog due to similarities in geology, mineralogy, and hydrology. Specifically, NTS shares many of the same geologic units as Yucca Mountain. The mineralogy consists of fractured volcanic tuffs and alluvium which is the same mineralogy found at the Yucca Mountain site. Therefore, colloid transport parameters measured at NTS are applicable to Yucca Mountain (DTNs: LA0303PR831352.002 [DIRS 163136]; LA0403PR831352.001 [DIRS 171416]).

NOTE 2: Most of the field-scale attachment/detachment rates and retardation factors for colloids in alluvial material data are obtained from outside sources. These data appeared in a scientific journal, *Water Resources Research*, in an article entitled "Modeling Removal of Bacteriophages MS2 and PRD1 by Dune Recharge at Castricum, Netherlands" (Schijven et al. 1999 [DIRS 162423]). Articles appearing in *Water Resources Research* undergo a peer review process, which enhances confidence that the data source is reliable. J. Schijven is from the Microbiological Laboratory for Health Protection, National Institute of Public Health and the Environment, Bilthoven, Netherlands; W. Hoogenboezem is from PWN Water Supply Company North-Holland, Bloemendaal, Netherlands; S. Hassanizadeh is from Faculty of Civil Engineering and Geosciences, Delft University of Technology, Delft, Netherlands; and J. Peters is from Kiwa Research and Consultancy, Nieuwegein, Netherlands. The fact that the authors of the journal article are associated with these institutions enhances confidence in the qualifications of personnel and the organizations generating the data. The data were used to estimate colloid-transport parameters in the saturated alluvium south of Yucca Mountain (with the exception of a detachment rate constant obtained in a single-well test at the Alluvial Testing Complex). Schijven et al. measured filtration and detachment rates for bacteriophages in alluvium material under natural gradient conditions (Schijven et al. 1999 [DIRS 162423], Table 3, p. 1107). They used bacteriophages denoted as MS-2 and PRD-1 that are in the same size range as colloids. These bacteriophages were chosen because they attach less than most pathogenic viruses and are relatively persistent during transport through the subsurface (Schijven et al. 1999 [DIRS 162423], p. 1101). Schijven et al. used a modeling approach very similar to RELAP to obtain colloid filtration and detachment rate constants from their field breakthrough curves. The model development and implementation is documented in detail. The groundwater at the site studied by Schijven et al. had somewhat higher divalent cation concentrations than most saturated zone waters in the vicinity of Yucca Mountain (90 to 100 mg/L Ca^{2+} and 10 to15 mg/L Mg^{2+} compared to 2 to 20 mg/L Ca^{2+} and 0 to 5 mg/L Mg^{2+} at Yucca Mountain), so colloids would be expected to be less stable at their site (Schijven et al. 1999 [DIRS 162423], Table 2, p. 1105). However, the alluvium material at their study site was also coarser (hydraulic conductivity of 12 m/day compared to 7.7 m/day for core permeability estimates at Yucca Mountain), with more sand, less clay, and more organic carbon than the alluvium material south of Yucca Mountain, all of which would tend to result in enhanced colloid transport relative to Yucca Mountain conditions. Thus, the combination of colloid selection, interpretive method, documentation quality, groundwater chemistry, and alluvium characteristics in the study of Schijven et al. make it possible to use their reported colloid filtration and detachment rate constants in the development of colloid-transport parameter distributions for Yucca Mountain alluvium. (AP-SIII.9Q, *Scientific Analyses*, first three bullets of Item L, Section 5.2.1.)

NTS=Nevada Test Site; UGTA=underground test area

[No changes to Sections 4.2 and 4.3]



DTNs: LA0303PR831231.003 [DIRS 163756] (analysis of C-wells rate constants); LA0303PR831352.002 [DIRS 163136] (analysis of ER-20-6 rate constants); LA0403PR831352.001 [DIRS 171416] (analysis of laboratory rate constants). [Note that several DTNs have been removed]

Source: Attachment A

NOTE: "ER-20-6" refers to the BULLION forced-gradient experiment (Reimus and Haga 1999 [DIRS 154705], p. 1). "C-wells BF" and "C-wells PP" refer to tests in the Bullfrog Tuff and Prow Pass Tuff (both members of the Crater Flat Group), respectively, at the UE-25 C-wells (BSC 2004 [DIRS 170010], Section 6). The experiments were conducted in the laboratory using fractured cores from Pahute Mesa at the Nevada Test Site. It is important to emphasize that different CML microspheres were used in the different field tests and, also, the groundwater chemistry varied from site–to-site or test-to-test. The dashed line on the figure has a slope of –1in log space.

BF=Bullfrog Tuff; PP=Prow Pass Tuff

Figure 6-1. CML Microsphere and Inorganic Colloid Filtration Rate Constants as a Function of Time to Solute Peak Concentration in Several Field and Laboratory Tracer Tests in Saturated, Fractured Media

No assumptions were required about the travel distance. Although these assumptions cannot be verified directly, they allow us to estimate a filtration rate constant using the following expression:

$$1\times10^{-5} = \text{Exp}[-(30)(365.25)(24)k_{filt}] \qquad \text{(Eq.6-4)}$$

where

1×10^{-5} = fraction of colloids traveling from the source to the ER-20-5 wells
(30)(365.25)(24) = 262,980 = transport time in hours.

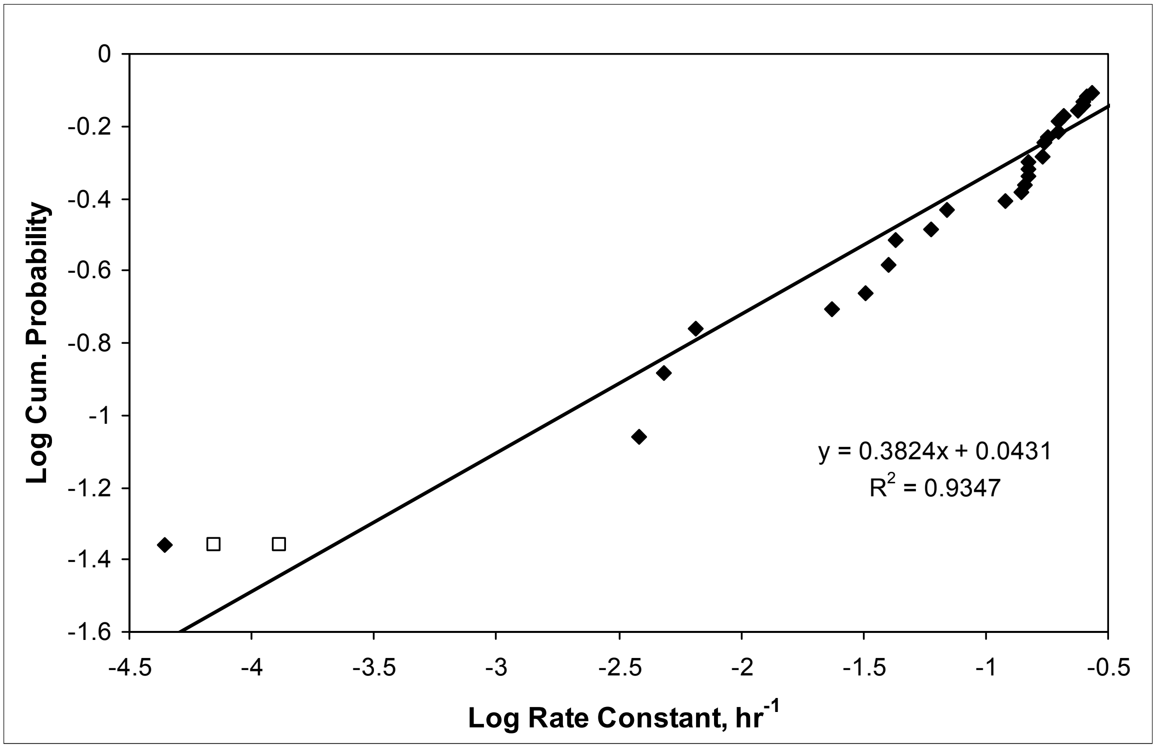
Note that Equation 6-4 assumes that the colloid concentration as a function of time in the water flowing from the source location is given by $dC/dt = -k_{filt}C$ (i.e., the concentration decreases according to a first order filtration reaction irrespective of advection and dispersion and ignoring detachment). Solution of this equation with the initial condition C = Co at t = 0 yields $C/Co = \exp(-k_{filt}t)$. Equation 6-4 is obtained by inserting 1×10^{-5} for C/Co and 30 years (converted to hours) for t.

Solving Equation 6-4 for k_{filt} yields a filtration rate constant of 4.4×10^{-5} hr^{-1}. This estimate is not very sensitive to the fraction of colloids assumed on the left-hand side of Equation 6-4. If the fraction is changed to 1×10^{-8}, the filtration rate constant becomes 7×10^{-5} hr^{-1}. The filtration rate constant is inversely proportional to the assumed transport time; consequently, if the transport time is decreased by a factor of 3 to 10 years, the filtration rate constant increases by a factor of 3 to 1.3×10^{-4} hr^{-1}.

Figure 6-2 shows the resulting cumulative probability distribution of filtration rate constants that includes the data point corresponding to the ER-20-5 observations (which was weighted the same as the field tracer test results). Both axes in Figure 6-2 are logarithmic. Note that data points associated with the two alternative scenarios discussed above for the ER-20-5 observations are also shown in Figure 6-2 (as squares) to illustrate the insensitivity of the overall cumulative distribution to these assumptions. However, these points are not used in the fit.

6.4.3 Colloid Retardation Factors for Fractured Volcanics

Using the interpretive results from all the tests represented in Figure 6-2, with the exception of the ER-20-5 observations and two of the three CML microsphere responses from the BULLION forced-gradient experiment (Reimus and Haga 1999 [DIRS 154705], pp. 29 to 31, Figures 13-15), a cumulative probability distribution for R_{col} can be generated. This distribution is provided in Table 6-2 and shown in Figure 6-3 (log scale on *x* axis), which again has the field test results weighted a factor of two greater than the laboratory test results. Table 6-2 and Figure 6-3 contain three cumulative probability distributions. The first distribution consists of the best-fitting R_{col} values obtained from RELAP (taken from the input DTNs listed in Figure 6-1). The second distribution is a truncated version of this CDF in which all retardation factors less than 6 are set equal to 6. The final distribution is the CDF used by TSPA, which captures the same trends as the truncated CDF while using fewer points.



Source: Attachment A

NOTE: The two squares show the effect of changing the assumptions associated with the filtration rate constant estimates for the ER-20-5 observations (see text).

Figure 6-2. Cumulative Probability Distribution of Log Colloid Filtration Rate Constants for Fractured Media

The CDF for TSPA represents the *uncertainty* in the retardation factor for colloids in the volcanic units. These values of retardation factors in the CDF can be applied on a log scale for the purposes of TSPA. The rationale for truncating the original CDF at $R_{col} = 6$ is that 6 is the smallest value of R_{col} that is reasonably well constrained by fitting the tails of colloid breakthrough curves. R_{col} values less than 6 were poorly constrained because the breakthrough curves had relatively high recoveries and tails with low concentrations that could be fitted quite well over a wide range of R_{col} values (the fits were much more sensitive to k_{filt} than R_{col}). In the extreme case of tests with nearly complete colloid recoveries and low tail concentrations, the breakthrough curves could be fit equally well with $R_{col} = 1$ and k_{filt} = anything or with R_{col} = a very large number and k_{filt} = a very small number. In either case, the implication is that there is no filtration, and the test data, in effect, provide no constraint whatsoever on R_{col} or k_{filt}. The fact that retardation factors smaller than 6 have been reported in tests is attributed to slow filtration rate constants that result in a fraction of the colloids moving conservatively through flow systems. The approach advocated here is to account for this unretarded fraction of colloids using a distribution of observed filtration rate constants, with unretarded colloids having the slowest rates. It is then assumed that all colloids that become filtered experience some minimum delay in the system as a result of filtration and detachment processes. This minimum delay in the fractured volcanics corresponds to a retardation factor of 6.

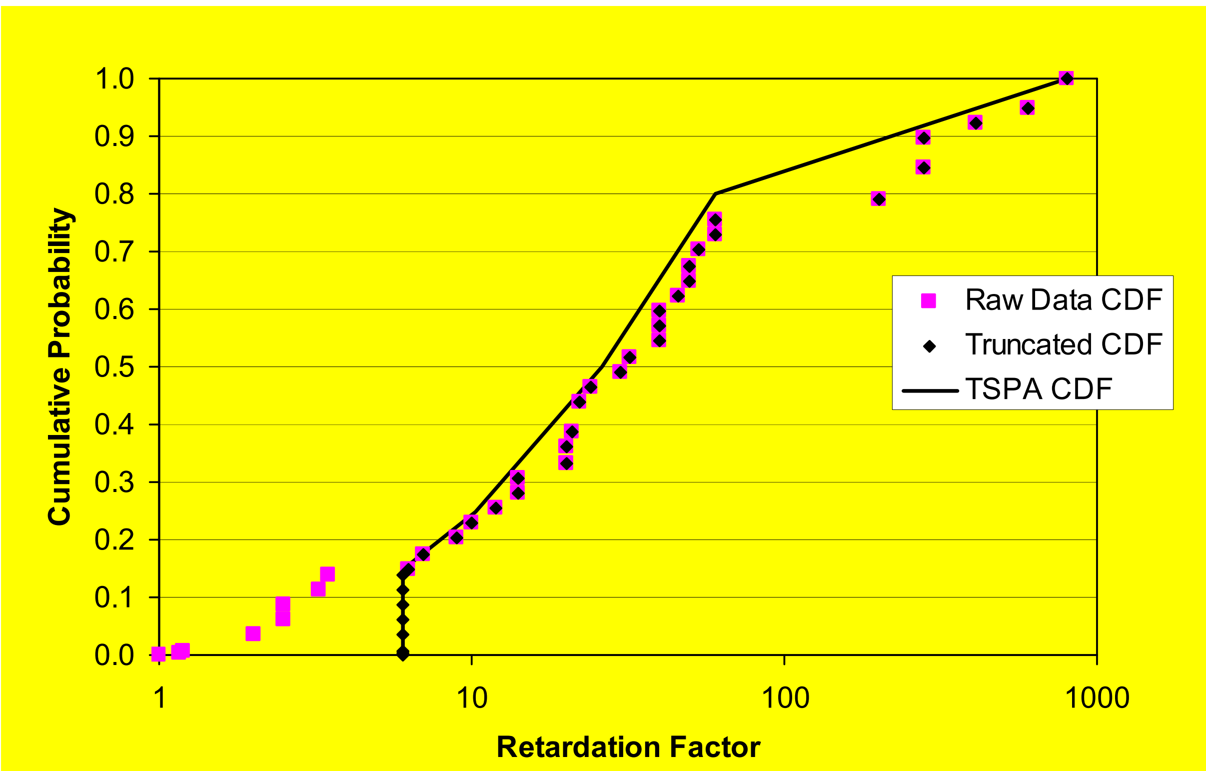
Table 6-2. Retardation Factor, R_{col}, Cumulative Probability Distributions for Fractured Volcanics

Raw Data CDF		Truncated CDF		CDF for TSPA	
Retardation Factor	**Cumulative Probability**	**Retardation Factor**	**Cumulative Probability**	**Retardation Factor**	**Cumulative Probability**
1	1.00E-05	6	1.00E-05	6.00	0
1.162	1.84E-03	6	1.84E-03	6.00	0.15
1.19	7.98E-03	6	7.98E-03	10.23	0.25
2	3.43E-02	6	3.43E-02	26.00	0.5
2.5	6.06E-02	6	6.06E-02	59.98	0.8
2.5	8.69E-02	6	8.69E-02	800.00	1
3.25	1.13E-01	6	1.13E-01		
3.5	1.40E-01	6	1.40E-01		
6.3	1.49E-01	6.3	1.49E-01		
7	1.76E-01	7	1.76E-01		
9	2.02E-01	9	2.02E-01		
10	2.28E-01	10	2.28E-01		
12	2.54E-01	12	2.54E-01		
14	2.81E-01	14	2.81E-01		
14	3.07E-01	14	3.07E-01		
20	3.33E-01	20	3.33E-01		
20	3.60E-01	20	3.60E-01		
21	3.86E-01	21	3.86E-01		
22	4.39E-01	22	4.39E-01		
24	4.65E-01	24	4.65E-01		
30	4.91E-01	30	4.91E-01		
32	5.18E-01	32	5.18E-01		
40	5.44E-01	40	5.44E-01		
40	5.70E-01	40	5.70E-01		
40	5.97E-01	40	5.97E-01		
46	6.23E-01	46	6.23E-01		
50	6.49E-01	50	6.49E-01		
50	6.76E-01	50	6.76E-01		
53	7.02E-01	53	7.02E-01		
60	7.28E-01	60	7.28E-01		
60	7.54E-01	60	7.54E-01		

Table 6-2. Retardation Factor, R_{col}, Cumulative Probability Distributions for Fractured Volcanics (continued)

Raw Data CDF		Truncated CDF	
Retardation Factor	**Cumulative Probability**	**Retardation Factor**	**Cumulative Probability**
200	7.91E-01	200	7.91E-01
280	8.44E-01	280	8.44E-01
280	8.97E-01	280	8.97E-01
410	9.23E-01	410	9.23E-01
600	9.49E-01	600	9.49E-01
800	1.00E+00	800	1.00E+00

Source: Attachment A



Source: Attachment A

NOTE: See text for recommendations on how to use the fits to generate stochastic retardation factors.

Figure 6-3. Truncated Cumulative Probability Distribution of Retardation Factors for the Fractured Volcanics

In these situations, RELAP would default to a best fit with R_{col} = ~1. R_{col} values greater than 1 but less than 6 were poorly constrained because they were associated with fits that were relatively insensitive to values of R_{col} and k_{filt}, although some combination of a low value of R_{col} and an intermediate value of k_{filt} offered the best least-squares fit.

The ER-20-5 observations were omitted from the R_{col} distribution(s) because it was assumed that k_{det} was zero when estimating k_{filt} (i.e., R_{col} = infinite). Also, the results from the two microsphere responses in the BULLION experiment production well were omitted because there was a significant increase in microsphere concentrations in the tails of the responses that apparently resulted from a flow transient in the production well. This increase prevented an unbiased estimate of k_{det}. The maximum retardation factor assumed for any of the colloid data sets was 1000. For any of these data sets, the factor of 1000 could effectively not be distinguished from an infinite retardation factor (R_{col} values greater than a few hundred in most cases were equivalent to assuming irreversible filtration, or R_{col} = infinite). Thus, the distribution of Figure 6-3 is probably conservative at the high end because of this somewhat arbitrary maximum value.

Figure 6-3 shows a fit to the cumulative distribution for retardation factors using the truncated data shown in Table 6-2. Note that the cumulative distribution of retardation factors in the volcanics has a lower limit of R_{col} = 6 (there is zero probability of having a retardation factor less than 6). This is believed to be a reasonable lower bound for retardation factors experienced by colloids that are reversibly filtered in the volcanics. The fact that retardation factors smaller than 6 have been observed in tests is attributed to slow filtration rate constants that result in a fraction of the colloids moving conservatively through flow systems. The approach advocated here is to account for this unretarded fraction of colloids using a distribution of observed filtration rate constants, with unretarded colloids having the slowest rates. It is then assumed that all colloids that become filtered experience some minimum delay in the system as a result of filtration and detachment processes. This minimum delay in the fractured volcanics corresponds to a retardation factor of 6.

6.5 COLLOID TRANSPORT IN ALLUVIAL MATERIAL

6.5.1 Background

Colloid filtration rate constants and retardation factors for alluvial material have been estimated in a number of laboratory experiments and one field experiment for the YMP (at NC-EWDP Site 22). Data from Schijven et al. were used to supplement the single YMP data point for field colloid filtration and detachment rates (Schijven et al. 1999 [DIRS 162423], Table 3, p. 1107). Laboratory column experiments in saturated alluvium have been conducted using silica and natural colloids in addition to CML microspheres.

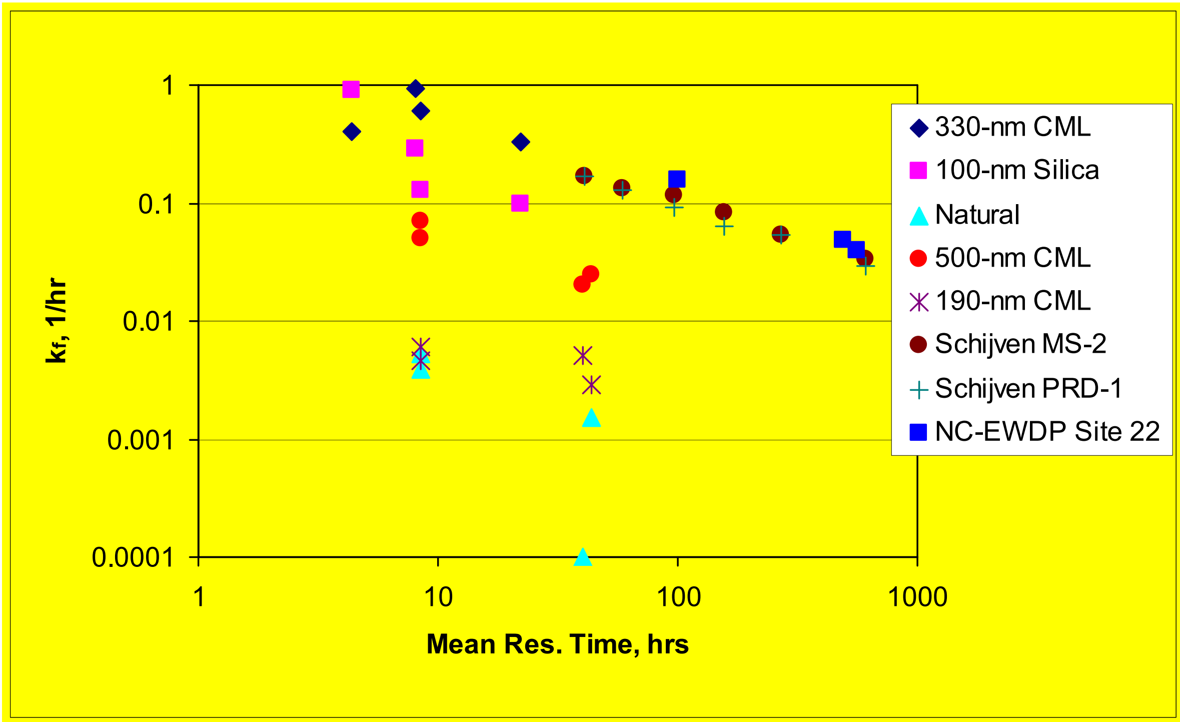
Schijven et al. measured filtration and detachment rates for bacteriophages in alluvial material under natural gradient conditions (Schijven et al. 1999 [DIRS 162423], Table 3, p. 1107). They used bacteriophages denoted as MS-2 and PRD-1 that are in the same size range as colloids. These bacteriophages were chosen because they attach less than most pathogenic viruses and are relatively persistent during transport through the subsurface (Schijven et al. 1999 [DIRS 162423], p. 1101). The groundwater at the site studied by Schijven et al. had somewhat higher divalent cation concentrations than most SZ waters in the vicinity of Yucca Mountain (90 to 100 mg/L Ca^{2+} and 10 to 15 mg/L Mg^{2+} compared to 2 to 20 mg/L Ca^{2+} and 0 to 5 mg/L Mg^{2+} at Yucca Mountain) (Schijven et al. 1999 [DIRS 162423], Table 2, p. 1105), so colloids would be expected to be less stable at their site. However, the alluvium material at their study site was also coarser, (hydraulic conductivity of 12 m/day compared to 7.7 m/day for core permeability estimates at Yucca Mountain) with more sand, less clay, and more organic carbon than the alluvium material south of Yucca Mountain, all of which would tend to result in enhanced colloid transport relative to Yucca Mountain conditions. Thus, the combination of colloid selection, groundwater chemistry, and alluvium characteristics at the site studied by Schijven et al. suggest that their reported colloid filtration and detachment rate constants can be applied to Yucca Mountain alluvium if the uncertainties associated with doing so are recognized.

As with the fractured volcanics, colloid filtration and detachment rate constants have been derived from colloid responses in tracer tests by using the advection-dispersion equation with appropriate terms for a single reversible first-order reaction to account for mass transfer between mobile water and immobile surfaces (filtration and detachment) to fit the data. Equations 6-1, 6-2, and 6-3 also apply to colloid filtration in the alluvium.

As was the case for the fractured volcanics, the values for V and D in Equations 6-1 and 6-2 were always obtained from interpretations of nonsorbing solute tracer responses; therefore, the filtration and detachment rate constants were the only parameters adjusted to match the colloid breakthrough curves.

6.5.2 Colloid Filtration Rate Constants in Alluvial Material

Figure 6-4 shows a plot of filtration rate constants obtained from interpretations of several laboratory tracer tests, the Schijven et al. field test conducted in saturated alluvium, and the cross-hole tracer test conducted at NC-EWDP Site 22 as a function of the mean solute residence time in the tests (Schijven et al. 1999 [DIRS 162423], Table 3, p. 1107). The filtration rate constants reflect the fraction of colloids that were not filtered during the tests (i.e., the rate constant is constrained primarily by the magnitude of the early arrival of colloids). Figure 6-4 shows that the field data from NC-EWDP Site 22 and from Schijven et al. (Schijven et al. 1999 [DIRS 162423], Table 3, p. 1107) are in remarkably good agreement. The figure also shows that there is an apparent trend of decreasing filtration rate constant with residence time, particularly when only a single type of colloid is considered. This trend is similar to the trend witnessed in the fractured volcanics. However, the experiments involving the two colloids with the largest filtration rate constants, the 330-nm CML microspheres and the 100-nm silica colloids, were conducted in columns in which air bubbles became apparent during the experiments. Later alluvium column experiments that involved the 190-nm and 500-nm CML microspheres, as well as the natural colloids, were conducted much more carefully to avoid air bubbles. It is certainly possible that the air bubbles in the earlier tests could have been at least partly responsible for the greater filtration rate constants in these tests. Figure 6-5 shows the resulting cumulative distribution function (CDF) of filtration rate constants in the alluvium. The filtration rate constants from the tracer test at NC-EWDP Site 22 were given twice the weight of all the other rate constants when this CDF was generated.



Source DTNs: LA0303PR831361.001 [DIRS 184301] (Analysis of all laboratory rate constants);

Source: Schijven et al. 1999 [162423] (MS-2 and PRD-1 rate constants from alluvium field test)

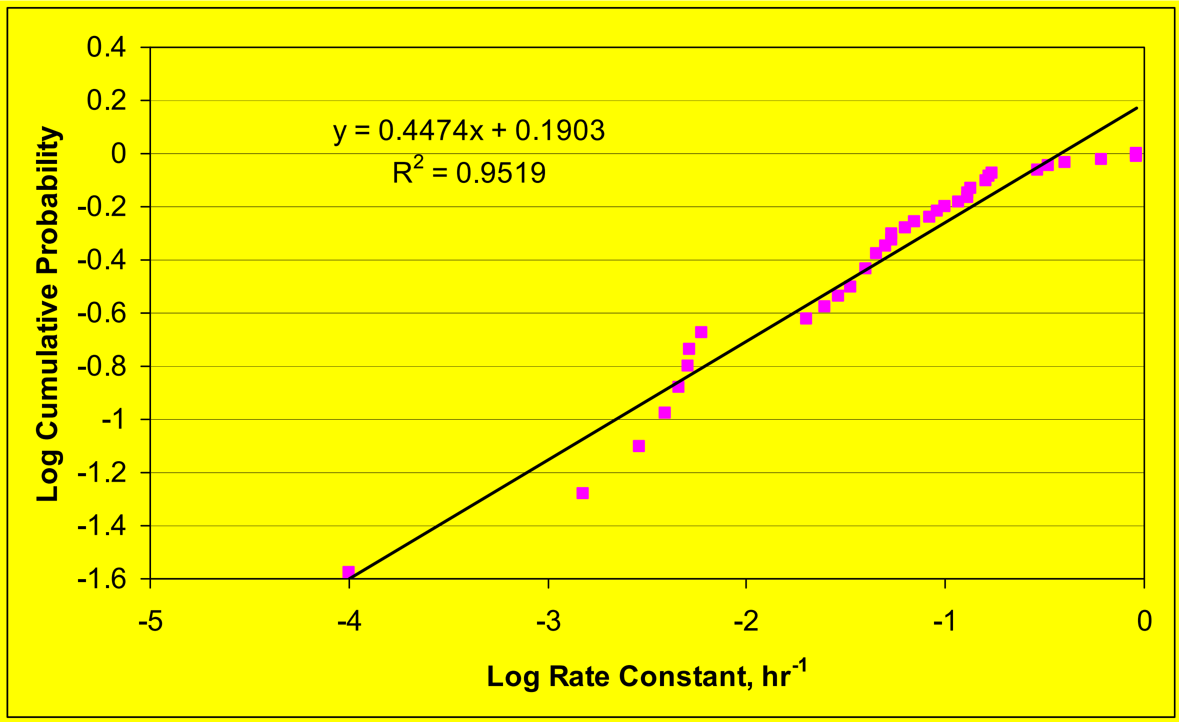
Source: Attachment A

NOTE: CML, Silica and Natural Colloids are rate constants obtained from alluvium packed columns and Schijven MS-2 and Schijven PRD-1 are rate constants from the alluvium field test.

Figure 6-4. Colloid Filtration Rate Constants, k_f, as a Function of Mean Residence Time in Several Laboratory Experiments and a Field Study in Saturated, Alluvium Material

6.5.3 Colloid Retardation Factors in Alluvial Material

As with the fractured volcanics, colloid retardation factors, R_{col}, can be determined from a RELAP fit, and the detachment rate is calculated using Equation 6-3. Using the interpretive results from all of the tests represented in Figure 6-4, a cumulative probability distribution for R_{col} can be generated. This distribution is provided in Table 6-3 and shown in Figure 6-6 (log scale on *x* axis). Table 6-3 and Figure 6-6 contain three cumulative probability distributions. The first distribution consists of the best-fitting R_{col} values obtained from RELAP (taken from the input DTNs listed in Figure 6-4). These values of retardation factors in the CDF can be applied on a log scale for TSPA purposes. The second distribution is a truncated version of this CDF in which all retardation factors less than eight are set equal to eight. This truncation was implemented for the same reasons that the R_{col} distribution for fractured volcanics was truncated (see Section 6.4.3). The final distribution is the CDF used by TSPA to simulate radionuclide retardation for the radionuclides that sorb irreversibly to colloids, which captures the same trends as the truncated CDF while using fewer points. The retardation factors from the tracer test at



Source: Attachment A

Figure 6-5. Cumulative Probability Distribution of Log Colloid Filtration Rate Constants in the Alluvium

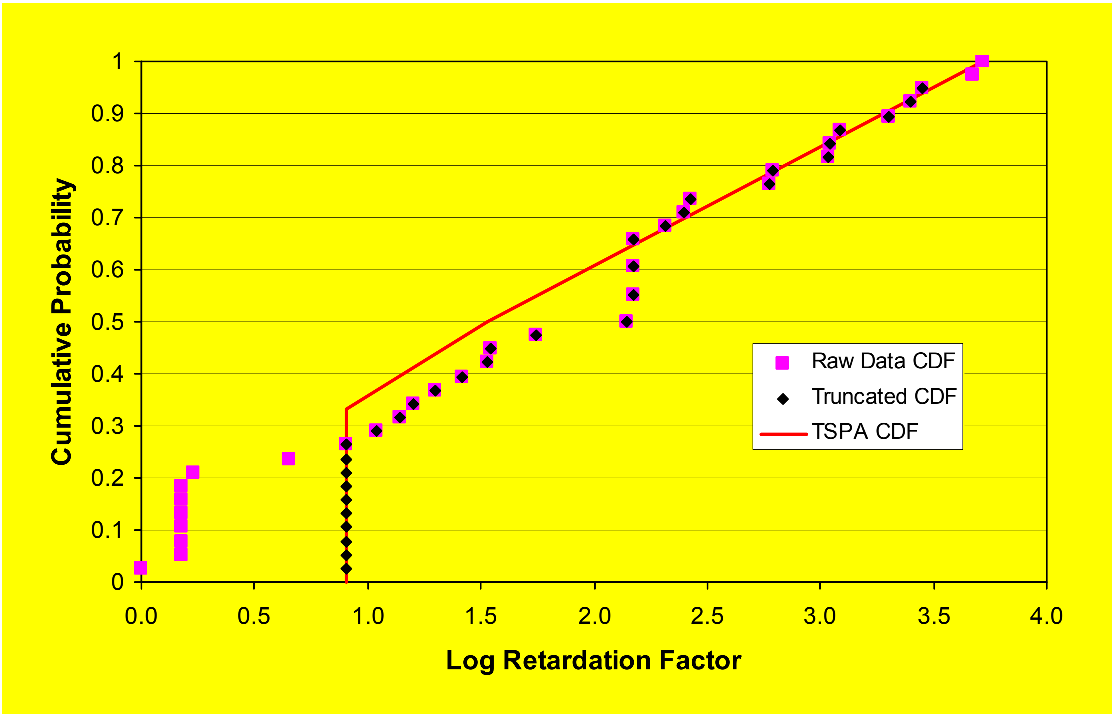
NC-EWDP Site 22 were given twice the weight of all the other retardation factors when this CDF was generated.

Note that the filtration rate constants and retardation factors from Schijven et al. (1999 [DIRS 162423], Table 3, p. 1107) are weighted the same as all lab experimental data when generating uncertainty distributions of filtration rate constants and retardation factors in the alluvium. Although the Schijven et al. data were obtained at field scales, the fact that the flow system and aquifer materials are different from Yucca Mountain justifies assigning no greater weight to these data than to data obtained from lab experiments using site-specific materials. Note that, as with the retardation factor distribution for the fractured volcanics, the alluvium retardation factor distribution is truncated at the lower end so that it has an effective minimum greater than one; in this case, the minimum is eight. The rationale for this minimum is the same as for the volcanics: that is, the colloids moving with smaller retardation factors are accounted for using a distribution of filtration rate constants, with unretarded colloids having the slowest rates; all colloids that become filtered experience some degree of retardation in the system as a result of filtration and detachment processes.

Table 6-3. Retardation Factor, R_{col}, Cumulative Probability Distributions for Alluvium

Raw Data CDF		**Truncated CDF**		**CDF for TSPA**	
Retardation Factor	**Probability**	**Retardation Factor**	**Probability**	**Retardation Factor**	**Probability**
1	0.026316	8	0.026316	8.00	0
1.5	0.052632	8	0.052632	8.00	0.331
1.5	0.078947	8	0.078947	33.96	0.5
1.5	0.105263	8	0.105263	5188.00	1
1.5	0.131579	8	0.131579		
1.5	0.157895	8	0.157895		
1.5	0.184211	8	0.184211		
1.7	0.210526	8	0.210526		
4.5	0.236842	8	0.236842		
8	0.263158	8	0.263158		
11	0.289474	11	0.289474		
14	0.315789	14	0.315789		
16	0.342105	16	0.342105		
20	0.368421	20	0.368421		
26	0.394737	26	0.394737		
34	0.421053	34	0.421053		
35	0.447368	35	0.447368		
55	0.473684	55	0.473684		
140	0.5	140	0.5		
150	0.552632	150	0.552632		
150	0.605263	150	0.605263		
150	0.657895	150	0.657895		
205.8824	0.684211	205.8824	0.684211		
250	0.710526	250	0.710526		
266.6667	0.736842	266.6667	0.736842		
600	0.763158	600	0.763158		
619.0476	0.789474	619.0476	0.789474		
1076.923	0.815789	1076.923	0.815789		
1111.111	0.842105	1111.111	0.842105		
1222.222	0.868421	1222.222	0.868421		
2000	0.894737	2000	0.894737		
2500	0.921053	2500	0.921053		
2818.182	0.947368	2818.182	0.947368		
4712.644	0.973684	4712.644	0.973684		
5194.805	1	5194.805	1		

Source: Attachment A



Source: Attachment A

Figure 6-6. Truncated Cumulative Probability Distribution of Log Retardation Factors in Alluvium

6.6 FRACTION OF COLLOIDS TRANSPORTING WITH NO RETARDATION

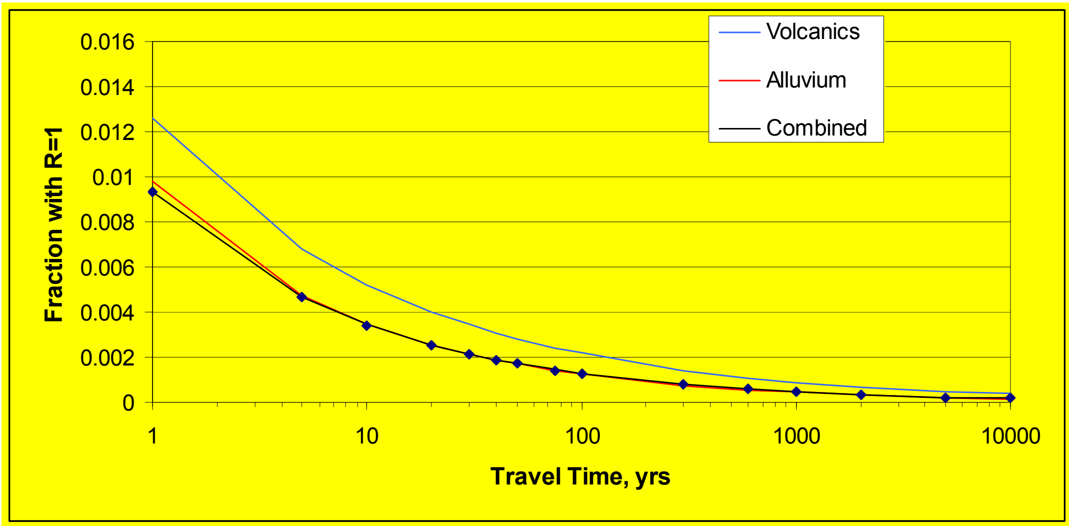
The majority of the colloids transport assuming reversible filtration given by the R_{col} distributions developed in Sections 6.4.3 and 6.5.3. However, as mentioned in Section 6.3, several field observations have suggested that a small percentage of colloids transport with essentially no retardation in groundwater, whereas the majority undergo either reversible or irreversible filtration, which can be described by a retardation factor, R_{col}. In this section, the cumulative probability distribution of colloids that travel with no retardation is developed. The attachment rate constant can be used to determine the fraction, *colfrac*, of the colloids that transport with no retardation. Specifically, colloids for which the reciprocal of the attachment rate constant is smaller than the transport time through the system will transport with no retardation. To determine the fraction of colloids that travel with no retardation, the critical rate constant, $k_{filt,crit}$ is calculated. This critical rate constant is simply one over the transport time through the system. The fraction of colloids that filter with this attachment rate constant is obtained from the cumulative probability distribution of attachment constants (Figure 6-2 for the fractured volcanics and Figure 6-5 for the alluvium). For the distribution of unretarded colloid fractions, water transport times through the UZ (which will include the effects of hydrologic fracture-matrix interactions), the SZ volcanics (in fractures only), and the SZ alluvium are added to obtain a combined transport time from the waste package to the accessible environment. Because the distributions for the fraction unretarded are so close for the volcanics and the alluvium, the volcanic and alluvium data are combined into a single distribution, resulting in slightly higher fractions for a given transport time than if the volcanic and alluvium uncertainty distributions had been considered separately.

The TSPA model utilizes the fast fraction model in the following manner. Travel time is uncertain through both the UZ and SZ, and the fast fraction model is also uncertain. Therefore, experimental evidence for this model does not warrant the use of a transport time distribution in TSPA. Instead, a conservative model is implemented. Uncertainty in the fraction of colloids that transport with no retardation is accommodated by using a conservative approach that assumes a combined transport time of 50 years in the unsaturated and saturated zone. This approach is conservative because it is expected that the combined transport time in the unsaturated zone and saturated zone will be more than 50 years—the median transit time in the saturated zone alone is expected to be longer than 100 years (BSC 2004 [DIRS 170042] Section 6.7.1). When combined with the unsaturated zone transit time, it is clear that the 50-year transport time is conservative for all but a few realizations. Table 6-4 and Figure 6-7 show the distribution of the fraction of colloids that travel with no retardation. For example, if the transport time is 50 years, the fraction of the total colloid mass transporting with no retardation would be 1.70×10^{-3}.

Table 6-4. Unretarded Fraction Cumulative Probability Distribution for the Fractured Volcanics and the Alluvium

Travel Time (Years)	Unretarded Fraction, colfrac
1	9.32E-03
5	4.63E-03
10	3.43E-03
20	2.54E-03
30	2.13E-03
40	1.88E-03
50	1.70E-03
75	1.43E-03
100	1.26E-03
300	7.83E-04
600	5.79E-04
1000	4.64E-04
2000	3.43E-04
5000	2.31E-04
10000	1.71E-04

Source: Attachment A



Source: Attachment A

Figure 6-7. Unretarded Fraction Cumulative Probability Distribution for the Fractured Volcanics, Alluvium, and the Combined Distribution of the Volcanics and Alluvium (diamonds correspond to an exponential fit to the combined curve)

6.7 VALIDITY OF THE LOCAL EQUILIBRIUM ASSUMPTION FOR COLLOIDS THAT ARE RETARDED

The majority fraction of colloids are retarded by the R_{col} uncertainty distributions developed in this analysis. The validity of the local equilibrium assumption must be tested to justify the use of the R_{col} distributions. Specifically, for Equation 6-3 to be valid, the local equilibrium assumption must hold. To evaluate the validity of this assumption, a simple analysis can be performed with nondimensional Damköhler numbers. The Damköhler number is simply the rate constant, k (1/hr), multiplied by a representative residence time, τ (hr), $Da = k\tau$. Bahr and Rubin demonstrate that the mass balance equation describing solute transport can be differentiated into an equilibrium and a kinetic component (Bahr and Rubin 1987 [DIRS 144539], p. 440, Equation 12). The smaller the kinetic component, the more accurate are the retardation factors based on the local equilibrium assumption. Note that the techniques utilized by Bahr and Rubin are commonly used in reactive transport systems to determine whether the local equilibrium assumption is valid (Bahr and Rubin 1987 [DIRS 144539]).

For evaluation of colloid behavior, Damköhler numbers, Da_{att} and Da_{det}, can be computed for attachment and detachment of colloids, respectively, using k_{filt} and k_{det}. The magnitude of the kinetic component is inversely proportional to Da_{att}+Da_{det}. Thus, the larger the sum of the two Damköhler numbers, the more appropriate the assumption of equilibrium. Bahr and Rubin (1987 [DIRS 144539]) found that equilibrium was well approximated when the sum of the two Damköhler numbers is greater than 100 and reasonably well estimated when the sum is greater than 10 (Bahr and Rubin 1987 [DIRS 144539], p. 450). Valocchi had a similar result, although he used only the reverse rate (detachment rate for colloids) to compute a Damköhler number (Valocchi 1985 [144579], pp. 812 to 813, Figure 2). Bahr and Rubin point out that the kinetic term can only be completely separated when the sum of the two Damköhler numbers is used (Bahr and Rubin 1987 [DIRS 144539]).

Table 6-14. Column Parameters in the CML Microsphere and Natural Colloid Experiments

	Length (cm)	Diameter (cm)	Range of Grain Size (microns)	Porosity (%)	Conductivity (cm/s)	Permeability (millidarcy)	Standard Deviation in Permeability (millidarcy)
Column C							
Pre-test[a]	30	2.50	75-2000	38.2	8.81×10^{-3}	9110	432
Post-test[b]	NM	NM	NM	NM	4.21×10^{-2}	43,600	597
Column D							
Pre-test[a]	30	2.50	125-2000	41.0	9.02×10^{-3}	9330	386
Post-test[b]	NM	NM	NM	NM	1.11×10^{-2}	11,500	599

DTN: LA0711PR150304.004 [DIRS 185425].

[a] Prior to both experiments in each column.

[b] After both experiments in each column.

NOTE: The two columns are designated C and D to distinguish them from Columns A and B discussed in Section 6.8.2.1 for the first set of alluvium column experiments.

NM = not measured.

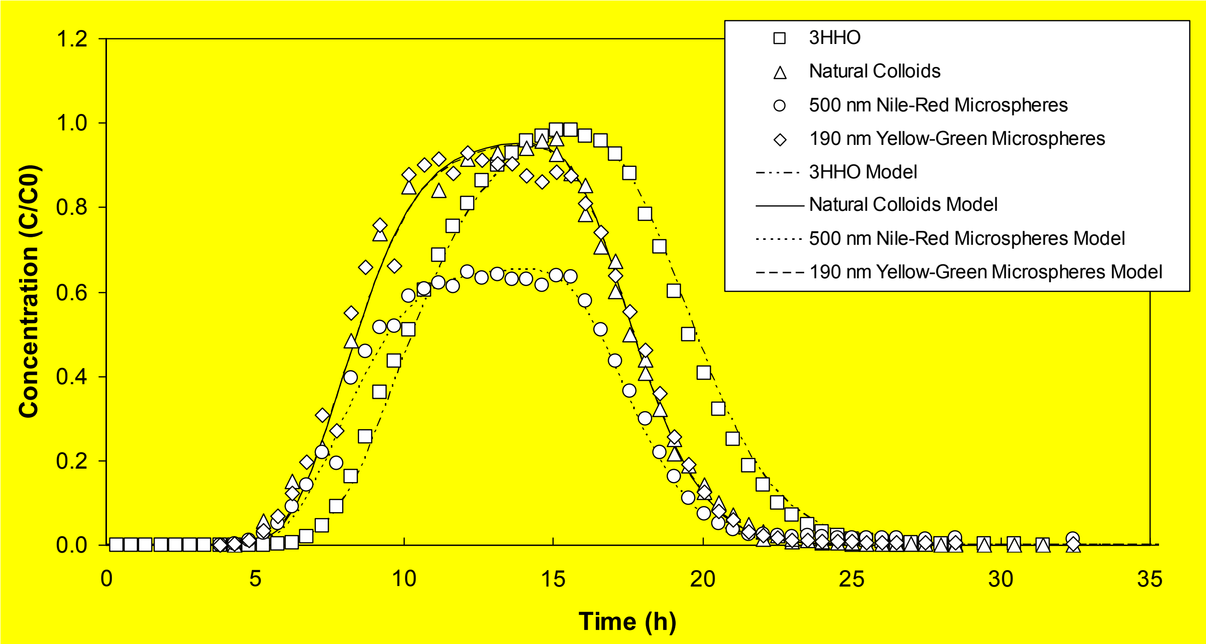
Table 6-15. Experimental Conditions in the CML Microsphere and Natural Colloid Experiments

Experiment	190-nm CML Concentration (mL^{-1})	500-nm CML Concentration (mL^{-1})	Natural Colloid Concentration (mL^{-1})	^{3}HHO Concentration (CPM/mL)	Injection Pulse Volume (mL)	Flow Rate (mL/hr)
Test 1, Column C	3.58×10^{6}	5.82×10^{5}	2.92×10^{10}	1.57×10^{5}	56.70	6.01
Test 1, Column D	3.55×10^{6}	5.78×10^{5}	2.93×10^{10}	1.57×10^{5}	56.02	5.93
Test 2, Column C	3.15×10^{6}	4.97×10^{5}	2.98×10^{10}	4.54×10^{5}	58.25	1.19
Test 2, Column D	3.14×10^{6}	5.13×10^{5}	2.98×10^{10}	4.54×10^{5}	56.94	1.19

DTN: LA0711PR150304.004 [DIRS 185425].

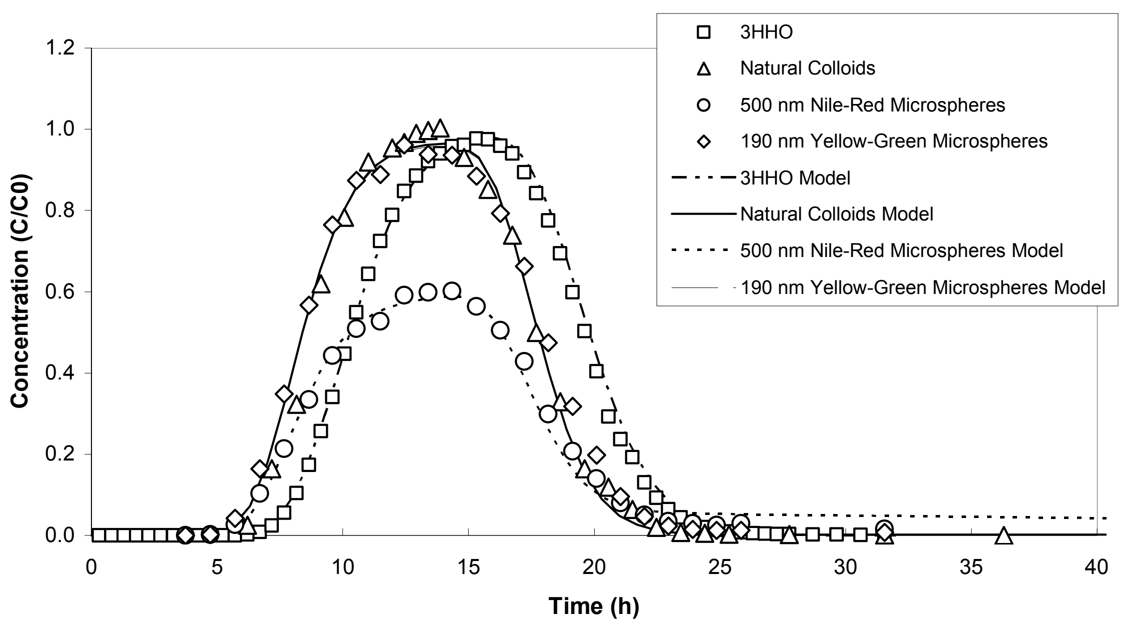
NOTE: CPM = counts per minute.

The experiments were interpreted in the same way as the first set of colloid transport experiments in alluvium-packed columns (i.e., first, the mean residence time and Peclet number of ^{3}HHO in each experiment was determined using the RELAP computer code (STN: 10551-2.0-00), and then colloid filtration rate constants and retardation factors were determined for the colloids assuming that the ^{3}HHO Peclet numbers applied to the colloids). The mean residence times of the colloids were allowed to be adjusted because the colloids broke through the columns significantly earlier than the ^{3}HHO in three of the four experiments. The breakthrough curves of the ^{3}HHO and colloids in each experiment are shown in Figures 6-17 through 6-20. Also shown in these figures are the RELAP fits to each data set. The ^{3}HHO and colloid transport parameters obtained from the fits are listed in Table 6-16.



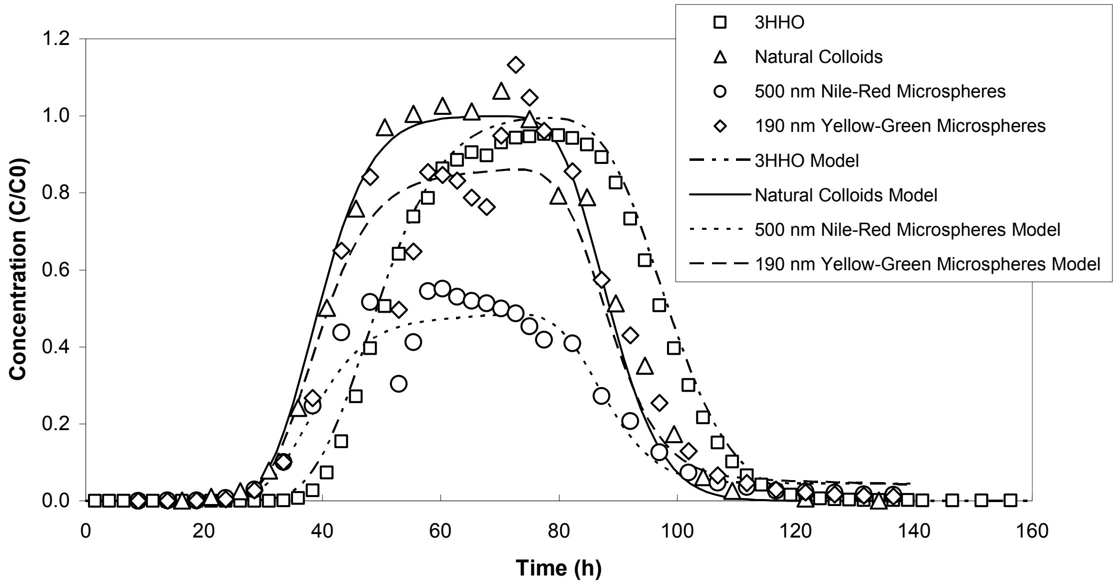
DTNs: LA0711PR150304.004 [DIRS 185425]; LA0303PR831361.001 [DIRS 184301].

Figure 6-17. ^{3}HHO and Colloid Breakthrough Curves and RELAP Fits in Test 1, Column C (6.01 mL/hr Flow Rate)



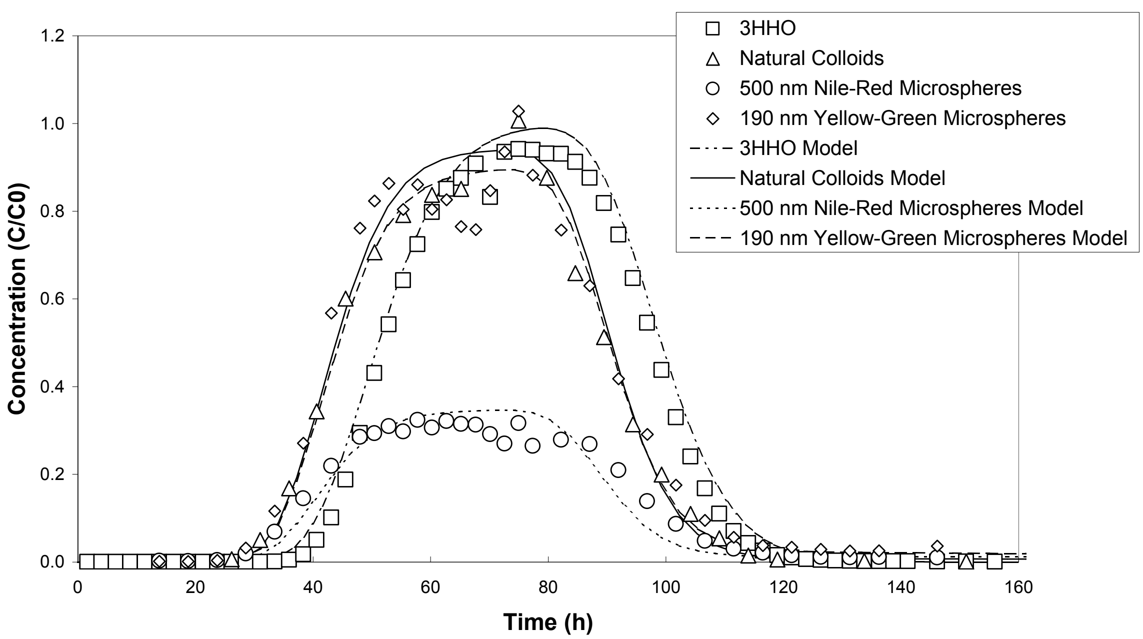
DTNs: LA0711PR150304.004 [DIRS 185425]; LA0303PR831361.001[DIRS 184301].

Figure 6-18. ^{3}HHO and Colloid Breakthrough Curves and RELAP Fits in Test 1, Column D (5.93 mL/hr Flow Rate)



DTNs: LA0711PR150304.004 [DIRS 185425]; LA0303PR831361.001[DIRS 184301].

Figure 6-19. ³HHO and Colloid Breakthrough Curves and RELAP Fits in Test 2, Column C (1.19 mL/hr Flow Rate)



DTNs: LA0711PR150304.004 [DIRS 185425]; LA0303PR831361.001[DIRS 184301].

Figure 6-20. ³HHO and Colloid Breakthrough Curves and RELAP fits in Test 2, Column D (1.19 mL/hr Flow Rate)

Table 6-16. Model Parameters from RELAP Fits of Tracer Breakthrough Curves in CML Microsphere and Natural Colloid Experiments in Saturated Alluvium

Model Parameter	Flow Rate (mL/hr), Column			
	6.01, Col. C	5.93, Col. D	1.19, Col. C	1.19, Col. D
^{3}HHO Mean Residence Time (hr)	10.5	10.5	50	52
^{3}HHO (and Colloid) Peclet Number	46	52	64	60
Colloid Mean Residence Time (hr)	8.5	8.5	40	44
190-nm CML Filtration Rate Constant (hr^{-1})	0.0060	0.0046	0.0051	0.0029
190-nm CML Retardation Factor	1.5 [a]	1.5 [a]	1.5	1.5 [a]
500-nm CML Filtration Rate Constant (hr^{-1})	0.05	0.07	0.02	0.025
500-nm CML Retardation Factor	11	4.5	8	35
Natural Colloid Filtration Rate Constant (hr^{-1})	0.0052	0.0039	0	0.0015
Natural Colloid Retardation Factor	1.7 [a]	1.5 [a]	1 [a]	1.5 [a]

DTN: LA0303PR831361.001 [DIRS 184301].

[a] The RELAP fits for these cases are extremely insensitive to the retardation factor. Any value between 1 and 1000 offers a good fit to the data provided the filtration rate constants are the values listed.

It is apparent from Figures 6-17 to 6-20 and Table 6-16 that both of the CML microspheres transported through the saturated alluvium columns with much less filtration than in the earlier experiments conducted using 330-nm diameter CML and 100-nm diameter silica microspheres (Section 6.8.2.1). The natural colloids also transported with much less filtration than the silica colloids in these experiments. There are two plausible explanations for the significant differences in colloid transport behavior in the two sets of experiments: 1) air bubbles in the columns in the first set of experiments may have significantly attenuated the colloids by providing air-water interfaces that irreversibly trapped the colloids, and 2) the higher divalent cation concentrations in the water used in the earlier experiments may have destabilized the colloids or at least made them more susceptible to attachment to alluvium surfaces. Although the amount of colloid filtration was significantly different in the two sets of alluvium colloid-transport experiments, the results were consistent in that the inorganic colloids transported with similar or less filtration than the CML microspheres in both sets of tests. However, it was also apparent in the second set of experiments that smaller CML microspheres tend to approximate more closely the transport behavior of natural inorganic colloids than larger microspheres in saturated alluvium. This result supports the hypothesis put forth at the end of Section 6.8.2.1 that interception may be a dominant mechanism of colloid filtration in alluvium because of the small pore throat sizes that are present. It also suggests that the smallest detectable CML microspheres should be used in field tracer tests in saturated alluvium to obtain field-scale colloid-transport parameters that are most representative of natural colloids. The uncertainty in colloid transport in alluvium is preserved by including both sets of experimental results in the overall data set used to develop the cumulative probability distributions for colloid filtration rate constants and for colloid retardation factors, as shown in Figures 6-5 and 6-6.

7. CONCLUSIONS

7.1 SUMMARY OF SCIENTIFIC ANALYSIS

This analysis report provides CDFs for the uncertainty in the colloid retardation factors in both the saturated volcanics and saturated alluvium (Attachment A) for use in TSPA simulations to account for the transport of radionuclides that are irreversibly sorbed to colloids. These retardation factors, R_{col}, represent the reversible chemical and physical filtration of colloids in the SZ. Interpretation of laboratory and field filtration rate constants (attachment and detachment rate constants) are used to determine the retardation factor distribution. The value of R_{col} is dependent on several factors such as colloid size, colloid type, and geochemical conditions (e.g., pH, Eh, and ionic strength). These factors are folded into the distribution of R_{col} that has been developed from field and experimental data collected under varying geochemical conditions with different colloid types and sizes. Attachment rate constants, k_{att}, and detachment rate constants, k_{det}, of colloids to the rock matrix have been determined from laboratory and field experiments, and separate R_{col} uncertainty distributions have been developed for the fractured volcanics and the alluvium. This report also describes a method for calculating a small fraction of colloids (and radionuclides that are irreversibly sorbed to colloids) that transport unretarded through the SZ as a function of groundwater transport time (Source: Attachment A). It is recommended that the combined groundwater transport time through the UZ and SZ (volcanics plus alluvium) be used to obtain an overall fraction of colloids that travels unretarded through the entire natural barrier system.

The transport of colloids is one of the processes that controls the transport of radionuclides through the natural barrier system. Therefore, the process of colloid transport is included in the transport model and is important in evaluating the contribution of the SZ to the natural barrier system. The specific acceptance criteria that relate to this report are discussed in Section 4.2.

The use of a retardation factor to describe colloid transport through the SZ implicitly assumes that colloid filtration and detachment rates are fast relative to groundwater transport times through the system. This assumption is shown to be valid for 94 percent of the colloid mass based on distributions of filtration rate constants from laboratory and field colloid transport experiments.

This analysis report also serves to document laboratory experiments conducted to evaluate the applicability of CML microspheres as field-test surrogates for inorganic colloids in both saturated fractured media and saturated alluvium. In fracture experiments, 330-nm diameter CML microspheres consistently experienced less filtration/attenuation than 100-nm silica colloids. In alluvium-packed column experiments, natural colloids (wide range of diameters, most less than 100 nm) transported with slightly less filtration than 190-nm diameter CML microspheres and with considerably less filtration than 500-nm microspheres. These results suggest that 1) small (less than 200-nm diameter) CML microspheres may serve as reasonable surrogates for inorganic colloids in saturated alluvium, and 2) CML microspheres may actually serve as conservative colloid tracers in saturated fractured media (yielding transport parameter estimates that result in overprediction of inorganic colloid transport).

The impact of the uncertainty of the distributions developed in this analysis on performance assessment is addressed in *SZ Flow and Transport Model Abstraction*; specifically, uncertainty in radionuclide transport is embodied in the breakthrough curves developed in Section 6.6 (BSC 2004 [DIRS 170042]).

7.4 OUTPUTS

Table 7-1 lists the output data for this scientific analysis report.

Table 7-1. Output Data

Data Description	Data Tracking Number	Location in Text
Colloid retardation factors for the saturated zone fractured volcanics	See Attachment A	Table 6-2
Colloid retardation factors for the saturated zone alluvium	See Attachment A	Table 6-3
Fraction of colloids that travel unretarded	See Attachment A	Table 6-4

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8.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

10 CFR 63. Energy: Disposal of High-Level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available. 156605

AP-2.22Q, Rev. 1, ICN 1. *Classification Analyses and Maintenance of the Q-List.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040714.0002.

AP-2.27Q, Rev. 1, ICN 4. *Planning for Science Activities.* Washington, D.C.: U.S. Department of Energy, Office of Civilian Radioactive Waste Management. ACC: DOC.20040610.0006.

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8.3 SOURCE DATA, LISTED BY DATA TRACKING NUMBER

~~LA0007PR831231.001. Bullfrog Reactive Tracer Test Data. Submittal date: 07/21/2000.~~ ~~156043~~

LA0206MH831361.001. Nye County Alluvial Testing Complex Column Experiment ATC COL A NCEWDP 19D1 25, 8/20/2001. Submittal date: 07/01/2002. 162426

LA0206MH831361.002. Nye County Alluvial Testing Complex Column Experiment ATC COL B NCEWDP 19D1 25, 8/8/2001. Submittal date: 07/01/2002. 162427

LA0206MH831361.003. Nye County Alluvial Testing Complex Column Experiment ATC COL A NCEWDP 19D1 25, 11/15/2001. Submittal date: 07/01/2002. 162428

LA0206MH831361.004. Nye County Alluvial Testing Complex Column Experiment ATC COL B NCEWDP 19D1 25, 11/15/2001. Submittal date: 07/01/2002. 162430

LA0711PR150304.004. Experiments on Pu (V)-Colloid Transport in Columns Packed with Material from Nye County Borehole 19D, Zone 4. Submittal date: 12/04/2007. [Was previously LA0301AA831352.001] 185425

LA0301PR831352.001. Breakthrough Curves of Iodide, CML Microspheres, and Silica Colloids in Saturated Fractured Cores from the Nevada Test Site. Submittal date: 01/23/2003. 162434

~~LA0301PR831361.003. Breakthrough Curves of Tritium, Plutonium, and Various Colloids in Saturated UE20C Fractured Cores from the Nevada Test Site. Submittal date: 01/22/2003.~~ ~~162435~~

~~LA0301PR831361.004. Breakthrough Curves of Tritium, Plutonium, and Various Colloids in Saturated PM-1 and PM-2 Fractured Cores from the Nevada Test Site. Submittal date: 01/22/2003.~~ ~~162436~~

~~LA0302PR831231.002. Solute Data from ER-20-6#2 in the BULLION Forced-Gradient Field Tracer Test at the ER-20-6 Wells at NTS. Submittal date: 02/03/2003.~~	~~162437~~
~~LA0302PR831231.003. Solute Data from ER-20-6#3 in the BULLION Forced-Gradient Field Tracer Test at the ER-20-6 Wells at NTS. Submittal date: 02/03/2003.~~	~~162438~~
~~LA0302PR831352.001. Transport of CML Microspheres in Field Tracer Test at ER-20-6#2 Site at the Nevada Test Site (NTS). Submittal date: 03/06/2003.~~	~~162439~~
~~LA0302PR831352.002. Transport of CML Microspheres in Field Tracer Test at ER-20-6#3 Site at the Nevada Test Site (NTS). Submittal date: 03/06/2003.~~	~~162440~~
LA0303PR831231.003. Model Interpretations of C-Wells Field Tracer Transport Experiments. Submittal date: 03/31/2003.	163756
LA0303PR831352.001. Calculations to Determine Detachment Rate Constant of Microspheres in a Single-Well Tracer Test in Saturated Alluvium. Submittal date: 03/31/2003.	163138
LA0303PR831352.002. Model Interpretations of ER-20-6 Field Tracer Transport Experiment. Submittal date: 03/31/2003.	163136
LA0303PR831361.001. RELAP V2.0 Model Interpretations of Solute and Colloid Transport in Alluvium-Packed Column Transport Experiments. Submittal date: 12/12/2007.	184301
LA0306PR831321.001. Mineralogy of ATC Colloids and Bentonite Drilling Muds. Submittal date: 06/03/2003.	164492
LA0403PR831352.001. Model Interpretations of NTS Fractured Core Colloid and Colloid-Facilitated Transport Experiments. Submittal date: 03/18/2004.	171416
LA0701PR150304.002. RELAP V2.0 Interpretations of Lithium, Bromide, 2,4,5 TFBA, 2,6 DFBA and Microsphere Breakthrough Curves in First Cross-Hole Tracer Test at NC-EWDP Site 22. Submittal date: 01/02/2007.	185424
~~LAPR831231AQ99.001. Prow Pass Reactive Tracer Test Field Data. Submittal date: 02/10/1999.~~	~~140134~~
MO0407SEPFEPLA.000. LA FEP List. Submittal date: 07/20/2004.	170760

8.4 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

~~DTN: LA0303HV831352.002. Colloid Retardation Factors for the Saturated Zone Fractured Volcanics.~~

~~DTN: LA0303HV831352.004. Colloid Retardation Factors for the Saturated Zone Alluvium.~~

~~DTN: LA0303HV831352.003. Fraction of Colloids that Travel Unretarded.~~