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Composite Analysis

Retention:
Permanent

DISTRIBUTION COEFFICIENTS (K_ds), K_d DISTRIBUTIONS, AND CELLULOSE DEGRADATION PRODUCT CORRECTION FACTORS FOR THE COMPOSITE ANALYSIS

Laura McDowell-Boyer
Daniel I. Kaplan

APRIL, 2009

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REVIEWS AND APPROVALS

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Revision 1 Summary

Revision Location	Revision Description
General	The denotation for Kaplan et al. 2008 was changed to Kaplan et al. 2008a due to the addition of another reference
Table 1	The Pu K_ds for oxidizing cement were changed based upon Kaplan 2007a, Kaplan and Coates 2007, and Kaplan et al. 2008a: • Young from 5000 to 10000 • Middle from 5000 to 10000 • Old from 500 to 10000
Table 1	The Tc K_ds for soil were changed based upon Kaplan et al. 2008b and Kaplan 2009: • Sandy from 0.1 to 0.6 • Clayey from 0.2 to 1.8
Table 1	Kaplan et al. 2008b and Kaplan 2009 were added as references for the soil K_ds of Tc
Table 2	The Tc K_ds for soil and their distribution were changed to be consistent with Table 1
Table 2	The Pu K_ds for oxidizing cement and their distribution were changed to be consistent with Table 1
Section 5.0 References	Kaplan et al. 2008b and Kaplan 2009 were added as references

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LIST OF ACRONYMS

Acronyms

CA	Composite Analysis
CDP	cellulose degradation products
FTF	F-Area Tank Farm
K_ds	Distributions coefficients
LLWF	Low-Level Waste Facility
PA	Performance Assessment
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
WSRC	Washington Savannah River Company

Abbreviations

%	percent
max	maximum
min	minimum
mL/g	milliliter per gram

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1.0 INTRODUCTION

The Savannah River National Laboratory (SRNL) is in the process of producing a Composite Analysis (CA) for the entire Savannah River Site (SRS). The SRS CA is an analysis of the projected dose to a hypothetical future member of the public resulting from the E-Area Low Level Waste Facility (LLWF), the Saltstone Disposal Facility (SDF), the closed F and H-Area Tank Farms (FTF and HTF), E-Area TRU Pad 1 disposal, and F-Area Materials Storage (FAMS), along with all other SRS radioactive source locations, which may interact with radionuclide transport from these facilities. The CA evaluates the dose to the public at points of assessment, which are selected based upon the site's land use plans, over a minimum 1,000 year period after all closures, facility deactivation & decommissioning (D&D), and waste site remediation have been completed and all DOE site operations have ceased. The inventory is based upon the projected end state conditions. The CA performance measures are a 100 mrem/year primary dose limit (USDOE Order 5400.5 (USDOE 1990)) and a 30 mrem/year administrative dose constraint.

SRNL has conducted extensive geochemical studies in support of SRS Performance Assessments and the SRS CA. In particular SRNL has conducted studies to determine site specific distribution coefficients (K_ds) for SRS soils and cementitious materials. This report provides K_ds, derived in large part from SRNL geochemical studies, to simulate sorption of radionuclides in soils and cementitious materials for use within the CA. It also provides information pertinent to the statistical distributions of these K_ds. Cellulose degradation product (CDP) correction factors, which account for the influence of CDPs, when present, on sorption, are also provided. The sections below briefly describe the source of the parameter values used, and the tables following these sections list values for the elements of interest in the CA. An Excel® workbook containing these values was produced for use within the CA models, and the tables below provide the contents of this workbook in a format designed to facilitate review of the parameter values.

2.0 DISTRIBUTION COEFFICIENTS FOR THE COMPOSITE ANALYSIS

Thirty-nine elements represent the radionuclides of interest in the CA. Thirty of these elements represent the 49 radionuclides to be analyzed in the CA, identified in the screening analysis (Taylor et al. 2008), and nine represent additional elements to be considered when radioactive daughters of these radionuclides are taken into account. Distribution coefficients (K_ds) for each of these elements were determined after a careful review of recent reports developed at the Savannah River Site (SRS) in support of Performance Assessments (PA) completed. K_d values for sandy soil, clayey soil, and cementitious materials of varying age and composition are given for these elements in Table 1. The "best value" estimates provide guidance on what the most likely K_d values are for a given condition (Kaplan 2007a).

K_d values were largely obtained from three sources: Kaplan 2007a, Kaplan 2007b, and Kaplan and Coates 2007. Values from these sources were used in carrying out the E-Area Low-Level Waste Facility (LLWF) PA and F-Area Tank Farm (FTF) PA (WSRC 2008a, 2008b). K_d values for I, Np, and Pu in cementitious materials were obtained from a study conducted for the Saltstone Disposal Facility PA (Kaplan et al. 2008a). For Tc, the K_ds most recently measured in SRS sediments (Kaplan et al. 2008b and Kaplan 2009) were used to estimate sorption coefficients for sandy and clayey soil. The chemical/mineralogical environments for which K_ds are available are sandy sediment, clayey sediment, oxidizing cement of three different ages, and reducing cement of three different ages. For seven elements, Bi, C, Ca, Lu, Pt, Tl, and Y, K_ds were not provided from the three references cited above for all of the environments. For all of these elements except C, the best analog for which a K_d value was available was determined based on valence and chemical group. These analogs are noted in the "Notes" column of Table 1. The K_ds for the analog were assigned from the indicated reference.

For the element carbon (C), a recent report (Roberts and Kaplan 2008) gives K_d values for sandy and clayey soils, and for 36-yr-old concrete and reducing grout. However, the value for the reducing grout from Roberts and Kaplan 2008 has been called into question by its authors due to its inconsistency with basic principles of C (more specifically carbonate) geochemistry and numerous other values summarized in Bradbury and Sarott (1995). At issue is that aqueous C-14 concentrations in contact with cementitious materials are well known to be controlled by solubility. The aqueous C-14 concentration that Roberts and Kaplan (2008) measured during the reducing grout K_d test was about two orders of magnitude greater than well established solubility values. Until the C-14 sorption test with reducing grout can be repeated, reducing grout will be assigned the same value as the 36-yr-old concrete from Roberts and Kaplan 2008, because it is more consistent with (and conservative with respect to) the values obtained from Bradbury and Sarott (1995) and because the presence of the reducing agent (i.e., the blast furnace slag) in the reducing grout has been reported by Bradbury and Sarott (1995) not to influence C-14 uptake.

3.0 K_d DISTRIBUTIONS

Associated with the "best value" K_ds given in Table 1 are parameters that address the expected variability associated with the K_d parameter. The range and distribution of K_d values for the E-Area LLWF PA are discussed and reported in Grogan et al. (2008). In this study by Grogan et al., multiple core sediment samples were taken from E-Area, K_d values were measured, and the results were used to estimate the statistical range and distribution of K_ds. The results indicate that "in terms of the distributions of K_d values, when the core was taken as a whole, all of the radionuclides were most closely log-normally distributed" (Grogan et al. 2008). The conclusions of this study can be further summarized as follows:

> "The 95-percentile range and type of distributions assigned to radionuclide K_d values should be assigned based on the following general rules. These general rules are derived from the measurements described in this report, some geochemical/geological consideration, and parsimony.
>
> - The 95% confidence level for the mean K_d was twice the mean in the Aquifer Zone, equal to the mean for the Upper Vadose Zone, and half the mean for the Lower Vadose Zone.
> - The distribution of K_d values was log normal in the Upper Vadose Zone and Aquifer Zone, and normal in the Lower Vadose Zone" (Grogan et al. 2008).

Based on these findings, the K_d distributions and ranges that are given in Tables 2 through 4 were developed, for sandy and clay sediments, oxidizing cement, and reducing cement environments, respectively. All distributions are assumed to be log-normal.

For sandy soils, it was assumed that the 95% confidence level for the mean K_d was 1.5 times the mean, which is a combination of the range for the Aquifer Zone and the Lower Vadose Zone. This would result in a calculation for the minimum ("Min") and maximum ("Max") values of the ranges as follows:

"Min" = K_d - $(1.5*0.5*K_d)$ = **$0.25*K_d$**
"Max" = K_d + $(1.5*0.5*K_d)$ = **$1.75*K_d$**

For clayey soils, it was assumed that the 95% confidence level for the mean K_d was 1.0 times the mean, which is corresponds to the range for the Upper Vadose Zone. This would result in a calculation for the minimum ("Min") and maximum ("Max") values of the ranges as follows:

"Min" = K_d – $(1.0*0.5*K_d)$ = **$0.5 * K_d$**

"Max" = K_d + $(1.0*0.5*K_d)$ = **$1.5*K_d$**

For cementitious environments, the distributions for sandy soil were assumed (i.e., a 95% confidence level of 1.5 times the mean).

4.0 CELLULOSE DEGRADATION PRODUCTS CORRECTION FACTOR

Correction factors to account for the influence of cellulose degradation products (CDP) on K_ds are provided in Table 5, for the 39 elements of interest in the CA. Many of these are derived from Kaplan (2007a), with the remainder being derived from Kaplan and Serkiz (2006). Correction factors greater than one indicate increased sorption in the presence of CDPs (Kaplan 2007a). The CDP correction factor is used to calculate a CDP-corrected K_d value, $K_{d,CDP}$ (Kaplan 2007a):

$$K_{d,CDP} = f_{CDP} \times K_d.$$

For elements that are not listed explicitly in Kaplan 2007a or Kaplan and Serkiz, 2006, characteristics of the element that suggests choice of analog are provided in the "Comments" column of Table 5. Analogs were chosen on the basis of these characteristics, using professional judgment. In cases where no analogs were identified (indicated as "None" in Table 5) the correction factor is assigned a value of one, for I and Tc (Kaplan and Serkiz 2006), or 0.5, for At and C (Kaplan 2007a), based on professional judgment. The K_ds for H and Rn are not affected by the presence of CDP, therefore no CDP correction is required and a factor of one is assigned to these elements.

Table 1. Best Value K_d's Recommended for Use in Composite Analysis

	Soil K_d (mL/g) [(1)]		Oxidizing Cement K_d (mL/g) [(1)]			Reducing Cement K_d (mL/g) [(1)]			K_d Reference		
Element	**Sandy**	**Clayey**	**Young**	**Middle**	**Old**	**Young**	**Middle**	**Old**	**Sand/Clay**	**Concrete**	**Notes** [(2)]
Ac	1100	8500	6000	6000	600	5000	5000	1000	Kaplan 2007a	Kaplan and Coates 2007	
Ag	60	150	1	1	0.1	1	1	0.1	Kaplan 2007b	Kaplan 2007b, Kaplan and Coates 2007	
Al	1300	1300	6000	6000	600	5000	5000	1000	Kaplan 2007b	Kaplan and Coates 2007	
Am	1100	8500	6000	6000	600	5000	5000	1000	Kaplan 2007a	Kaplan and Coates 2007	
At	1.00E-09	0.6	8	15	4	2	10	4	Kaplan 2007a	Kaplan and Coates 2007	
Ba	5	17	100	100	70	0.5	3	20	Kaplan 2007a	Kaplan and Coates 2007	
Bi	1100	8500	6000	6000	600	5000	5000	1000	Kaplan 2007a [(3)]	Kaplan and Coates 2007 [(3)]	trivalent, analog Am
C	10	400	3000	3000	3000	3000	3000	3000	Roberts and Kaplan 2008	Roberts and Kaplan 2008, Bradbury and Sarott 1995	Reducing cement assigned K_d consistent with Bradbury and Sarott 1995
Ca	5	17	3	30	15	0.5	3	20	Kaplan 2007a [(3)]	Kaplan and Coates 2007 [(3)]	alkali earth metal, analog Sr
Cd	4	10	4000	4000	1000	5000	5000	1000	Kaplan 2007b	Kaplan and Coates 2007	
Cf	1100	8500	6000	6000	600	5000	5000	1000	Kaplan 2007a	Kaplan and Coates 2007	
Cl	1.0E-09	1.0E-09	20	20	2	20	20	2	Kaplan 2007a	Kaplan and Coates 2007	
Cm	1100	8500	6000	6000	600	5000	5000	1000	Kaplan 2007a	Kaplan and Coates 2007	

	Soil K_d (mL/g) [1]		Oxidizing Cement K_d (mL/g) [1]			Reducing Cement K_d (mL/g) [1]			K_d Reference		
Element	**Sandy**	**Clayey**	**Young**	**Middle**	**Old**	**Young**	**Middle**	**Old**	**Sand/Clay**	**Concrete**	**Notes** [2]
Cs	50	250	2	20	10	1.0E-09	2	10	Kaplan 2007a	Kaplan and Coates 2007	
Fr	50	250	2	20	10	1.0E-09	2	10	Kaplan 2007a	Kaplan and Coates 2007	
H	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	Kaplan 2007a	Kaplan and Coates 2007	
I	1.0E-09	0.6	8	15	4	5	9	1.0E-09	Kaplan 2007a	Kaplan and Coates 2007, Kaplan et al. 2008a	Reducing cement assigned K_d from Kaplan et al. 2008a
K	10	60	2	20	10	1.0E-09	2	10	Kaplan 2007b	Kaplan and Coates 2007	
Lu	1100	8500	6000	6000	600	5000	5000	1000	Kaplan 2007a [3]	Kaplan and Coates 2007 [3]	trivalent transition metal, analog Am
Mo	6	120	0.1	0.1	0.1	0.1	0.1	0.1	Kaplan 2007b	Kaplan 2007b, Kaplan and Coates 2007	
Nb	1.0E-09	1.0E-09	1000	1000	500	1000	1000	500	Kaplan 2007a	Kaplan 2007a, Kaplan and Coates 2007	
Ni	7	30	4000	4000	1000	5000	5000	1000	Kaplan 2007a	Kaplan and Coates 2007	
Np	0.6	35	1600	1600	250	4000	4000	3000	Kaplan 2007a	Kaplan and Coates 2007, Kaplan et al. 2008a	Reducing cement assigned K_d from Kaplan et al. 2008a
Pa	0.6	35	1600	1600	250	5000	5000	500	Kaplan 2007a	Kaplan and Coates 2007	
Pb	2000	5000	500	500	250	500	500	250	Kaplan 2007a	Kaplan 2007a, Kaplan and Coates 2007	

	Soil K_d (mL/g) [(1)]		Oxidizing Cement K_d (mL/g) [(1)]			Reducing Cement K_d (mL/g) [(1)]			K_d Reference		
Element	**Sandy**	**Clayey**	**Young**	**Middle**	**Old**	**Young**	**Middle**	**Old**	**Sand/Clay**	**Concrete**	**Notes** [(2)]
Pd	7	30	4000	4000	1000	5000	5000	1000	Kaplan 2007b	Kaplan and Coates 2007	
Po	2000	5000	500	500	250	500	500	250	Kaplan 2007a	Kaplan 2007a, Kaplan and Coates 2007	
Pt	900	2000	5000	5000	500	5000	5000	500	Kaplan 2007a [(3)]	Kaplan 2007a [(3)]	tetravalent, analog Zr
Pu	270	5900	10000	10000	10000	10000	10000	10000	Kaplan 2007a	Kaplan and Coates 2007, Kaplan et al. 2008a	Reducing cement assigned K_d from Kaplan et al. 2008a See note [(4)] for source of old oxidizing cement K_d values
Ra	5	17	100	100	70	0.5	3	20	Kaplan 2007a	Kaplan and Coates 2007	
Rn	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	1.0E-09	Kaplan 2007a	Kaplan and Coates 2007	
Se	1000	1000	300	300	150	300	300	150	Kaplan 2007a	Kaplan 2007a, Kaplan and Coates 2007	
Sr	5	17	3	30	15	0.5	3	20	Kaplan 2007a	Kaplan and Coates 2007	
Tc	0.6	1.8	0.8	0.8	0.5	5000	5000	5000	Kaplan et al. 2008b and Kaplan 2009	Kaplan and Coates 2007	
Th	900	2000	5000	5000	500	5000	5000	500	Kaplan 2007a	Kaplan 2007a, Kaplan and Coates 2007	
Tl	60	150	1	1	0.1	1	1	0.1	Kaplan 2007b [(3)]	Kaplan and Coates 2007 [(3)]	monovalent, analog Ag

	Soil K_d (mL/g) [1]		Oxidizing Cement K_d (mL/g) [1]			Reducing Cement K_d (mL/g) [1]			K_d Reference		
Element	**Sandy**	**Clayey**	**Young**	**Middle**	**Old**	**Young**	**Middle**	**Old**	**Sand/Clay**	**Concrete**	**Notes [2]**
U	200	300	250	250	70	2500	2500	2500	Kaplan 2007a	Kaplan and Coates 2007	
Y	1100	8500	6000	6000	600	5000	5000	1000	Kaplan 2007a [3]	Kaplan and Coates 2007 [3]	trivalent transition metal, analog Am
Zr	900	2000	5000	5000	500	5000	5000	500	Kaplan 2007a	Kaplan 2007a, Kaplan and Coates 2007	

(1) Zero values represented as 1E-09 for computational purposes (to avoid divide by zero errors)
(2) Notes regarding analogs represent professional judgment
(3) Value for analog taken from cited reference
(4) Kaplan and Coates 2007 (Table 4) recommended best estimate Pu K_ds for stage 1 and 2 oxidizing concrete of 10,000 mL/g, while recommending a value of 1,000 for stage 3 oxidizing concrete. Kaplan and Coates 2007 (Table 4) also recommended best estimate Pu K_ds for stage 1 and 2 reducing concrete of 4,000 mL/g and that of 500 mL/g for stage 3 reducing concrete. However Kaplan and Coates 2007 (Table 3) documented an average measured Pu K_d for stage 3 oxidizing concrete of 92,200 mL/g. Based upon additional K_d measurements of reducing concrete, Kaplan et al. 2008a (Tables 4 and 5) recommended a best estimate Pu K_ds for stage 1, 2, and 3 reducing concrete of 10,000 mL/g. As noted by Kaplan 2007a, reducing concrete does not have a greater Pu K_d than oxidizing concrete. Since the measured Pu K_d for stage 3 oxidizing concrete averaged 92,200 mL/g (Kaplan and Coates 2007), the recommended Pu K_d for stage 3 reducing concrete is 10,000 mL/g (Kaplan et al. 2008a), and reducing concrete should not have a greater Pu K_d than oxidizing concrete (Kaplan 2007a), the Pu K_d for stage 3 oxidizing concrete will be taken as 10,000 mL/g.

Table 2. Composite Analysis K_d Distributions for Sandy and Clayey Soil [(1)]

Element	Sandy Soil				Clayey Soil			
	Best Value K_d (mL/g) [(2)]	Distribution	Minimum (mL/g) [(2)]	Maximum (mL/g) [(2)]	Best Value K_d (mL/g) [(2)]	Distribution	Minimum (mL/g) [(2)]	Maximum (mL/g) [(2)]
Ac	1100	Log-normal	275	1925	8500	Log-normal	4250	12750
Ag	60	Log-normal	15	105	150	Log-normal	75	225
Al	1300	Log-normal	325	2275	1300	Log-normal	650	1950
Am	1100	Log-normal	275	1925	8500	Log-normal	4250	12750
At	1E-09	Log-normal	1E-09	1E-09	0.6	Log-normal	0.3	0.9
Ba	5	Log-normal	1.25	8.75	17	Log-normal	8.5	25.5
Bi	1100	Log-normal	275	1925	8500	Log-normal	4250	12750
C	10	Log-normal	2.5	17.5	400	Log-normal	200	600
Ca	5	Log-normal	1.25	8.75	17	Log-normal	8.5	25.5
Cd	4	Log-normal	1	7	10	Log-normal	5	15
Cf	1100	Log-normal	275	1925	8500	Log-normal	4250	12750
Cl	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09
Cm	1100	Log-normal	275	1925	8500	Log-normal	4250	12750
Cs	50	Log-normal	12.5	87.5	250	Log-normal	125	375
Fr	50	Log-normal	12.5	87.5	250	Log-normal	125	375
H	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09
I	1E-09	Log-normal	1E-09	1E-09	0.6	Log-normal	0.3	0.9
K	10	Log-normal	2.5	17.5	60	Log-normal	30	90
Lu	1100	Log-normal	275	1925	8500	Log-normal	4250	12750
Mo	6	Log-normal	1.5	10.5	120	Log-normal	60	180
Nb	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09
Ni	7	Log-normal	1.75	12.25	30	Log-normal	15	45
Np	0.6	Log-normal	0.15	1.05	35	Log-normal	17.5	52.5
Pa	0.6	Log-normal	0.15	1.05	35	Log-normal	17.5	52.5
Pb	2000	Log-normal	500	3500	5000	Log-normal	2500	7500
Pd	7	Log-normal	1.75	12.25	30	Log-normal	15	45
Po	2000	Log-normal	500	3500	5000	Log-normal	2500	7500

Element	Sandy Soil				Clayey Soil			
	Best Value K_d (mL/g) [2]	Distribution	Minimum (mL/g) [2]	Maximum (mL/g) [2]	Best Value K_d (mL/g) [2]	Distribution	Minimum (mL/g) [2]	Maximum (mL/g) [2]
Pt	900	Log-normal	225	1575	2000	Log-normal	1000	3000
Pu	270	Log-normal	67.5	472.5	5900	Log-normal	2950	8850
Ra	5	Log-normal	1.25	8.75	17	Log-normal	8.5	25.5
Rn	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09
Se	1000	Log-normal	250	1750	1000	Log-normal	500	1500
Sr	5	Log-normal	1.25	8.75	17	Log-normal	8.5	25.5
Tc	0.6	Log-normal	0.15	1.05	1.8	Log-normal	0.9	2.7
Th	900	Log-normal	225	1575	2000	Log-normal	1000	3000
Tl	60	Log-normal	15	105	150	Log-normal	75	225
U	200	Log-normal	50	350	300	Log-normal	150	450
Y	1100	Log-normal	275	1925	8500	Log-normal	4250	12750
Zr	900	Log-normal	225	1575	2000	Log-normal	1000	3000

(1) Grogan et al., 2008, "Distribution of Sorption Coefficients (K_d Values) in the SRS Subsurface Environment", WSRC-STI-2008-00285
(2) Zero values represented as 1E-09 for computational purposes (to avoid divide by zero errors)

Table 3. Composite Analysis K_d Distributions for Oxidizing Cement [1]

Element	Young				Middle				Old			
	Best K_d [2,3]	Distribution	Min [2,3]	Max [2,3]	Best K_d [2,3]	Distribution	Min [2,3]	Max [2,3]	Best K_d [2,3]	Distribution	Min [2,3]	Max [2,3]
Ac	6000	Log-normal	1500	10500	6000	Log-normal	1500	10500	600	Log-normal	150	1050
Ag	1	Log-normal	0.25	1.75	1	Log-normal	0.25	1.75	0.1	Log-normal	0.025	0.175
Al	6000	Log-normal	1500	10500	6000	Log-normal	1500	10500	600	Log-normal	150	1050
Am	6000	Log-normal	1500	10500	6000	Log-normal	1500	10500	600	Log-normal	150	1050
At	8	Log-normal	2	14	15	Log-normal	3.75	26.25	4	Log-normal	1	7
Ba	100	Log-normal	25	175	100	Log-normal	25	175	70	Log-normal	17.5	122.5
Bi	6000	Log-normal	1500	10500	6000	Log-normal	1500	10500	600	Log-normal	150	1050
C	3000	Log-normal	750	5250	3000	Log-normal	750	5250	3000	Log-normal	750	5250
Ca	3	Log-normal	0.75	5.25	30	Log-normal	7.5	52.5	15	Log-normal	3.75	26.25
Cd	4000	Log-normal	1000	7000	4000	Log-normal	1000	7000	1000	Log-normal	250	1750
Cf	6000	Log-normal	1500	10500	6000	Log-normal	1500	10500	600	Log-normal	150	1050
Cl	20	Log-normal	5	35	20	Log-normal	5	35	2	Log-normal	0.5	3.5
Cm	6000	Log-normal	1500	10500	6000	Log-normal	1500	10500	600	Log-normal	150	1050
Cs	2	Log-normal	0.5	3.5	20	Log-normal	5	35	10	Log-normal	2.5	17.5
Fr	2	Log-normal	0.5	3.5	20	Log-normal	5	35	10	Log-normal	2.5	17.5
H	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09
I	8	Log-normal	2	14	15	Log-normal	3.75	26.25	4	Log-normal	1	7
K	2	Log-normal	0.5	3.5	20	Log-normal	5	35	10	Log-normal	2.5	17.5
Lu	6000	Log-normal	1500	10500	6000	Log-normal	1500	10500	600	Log-normal	150	1050
Mo	0.1	Log-normal	0.025	0.175	0.1	Log-normal	0.025	0.175	0.1	Log-normal	0.025	0.175
Nb	1000	Log-normal	250	1750	1000	Log-normal	250	1750	500	Log-normal	125	875
Ni	4000	Log-normal	1000	7000	4000	Log-normal	1000	7000	1000	Log-normal	250	1750
Np	1600	Log-normal	400	2800	1600	Log-normal	400	2800	250	Log-normal	62.5	437.5
Pa	1600	Log-normal	400	2800	1600	Log-normal	400	2800	250	Log-normal	62.5	437.5
Pb	500	Log-normal	125	875	500	Log-normal	125	875	250	Log-normal	62.5	437.5

Element	Young				Middle				Old			
	Best K_d (2,3)	Distribution	Min (2,3)	Max (2,3)	Best K_d (2,3)	Distribution	Min (2,3)	Max (2,3)	Best K_d (2,3)	Distribution	Min (2,3)	Max (2,3)
Pd	4000	Log-normal	1000	7000	4000	Log-normal	1000	7000	1000	Log-normal	250	1750
Po	500	Log-normal	125	875	500	Log-normal	125	875	250	Log-normal	62.5	437.5
Pt	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	500	Log-normal	125	875
Pu	10000	Log-normal	2500	17500	10000	Log-normal	2500	17500	10000	Log-normal	2500	17500
Ra	100	Log-normal	25	175	100	Log-normal	25	175	70	Log-normal	17.5	122.5
Rn	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09
Se	300	Log-normal	75	525	300	Log-normal	75	525	150	Log-normal	37.5	262.5
Sr	3	Log-normal	0.75	5.25	30	Log-normal	7.5	52.5	15	Log-normal	3.75	26.25
Tc	0.8	Log-normal	0.2	1.4	0.8	Log-normal	0.2	1.4	0.5	Log-normal	0.125	0.875
Th	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	500	Log-normal	125	875
Tl	1	Log-normal	0.25	1.75	1	Log-normal	0.25	1.75	0.1	Log-normal	0.025	0.175
U	250	Log-normal	62.5	437.5	250	Log-normal	62.5	437.5	70	Log-normal	17.5	122.5
Y	6000	Log-normal	1500	10500	6000	Log-normal	1500	10500	600	Log-normal	150	1050
Zr	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	500	Log-normal	125	875

(1) Grogan et al., 2008, "Distribution of Sorption Coefficients (K_d Values) in the SRS Subsurface Environment", WSRC-STI-2008-00285; extended same method for distributions in sandy soil to concrete K_ds.
(2) Zero values represented as 1E-09 for computational purposes (to avoid divide by zero errors)
(3) All values in mL/g

Table 4. Composite Analysis K_d Distributions for Reducing Cement [1]

Element	Young				Middle				Old			
	Best K_d [2,3]	Distribution	Min [2,3]	Max [2,3]	Best K_d [2,3]	Distribution	Min [2,3]	Max [2,3]	Best K_d [2,3]	Distribution	Min [2,3]	Max [2,3]
Ac	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
Ag	1	Log-normal	0.25	1.75	1	Log-normal	0.25	1.75	0.1	Log-normal	0.025	0.175
Al	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
Am	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
At	2	Log-normal	0.5	3.5	10	Log-normal	2.5	17.5	4	Log-normal	1	7
Ba	0.5	Log-normal	0.125	0.875	3	Log-normal	0.75	5.25	20	Log-normal	5	35
Bi	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
C	3000	Log-normal	750	5250	3000	Log-normal	750	5250	3000	Log-normal	750	5250
Ca	0.5	Log-normal	0.125	0.875	3	Log-normal	0.75	5.25	20	Log-normal	5	35
Cd	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
Cf	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
Cl	20	Log-normal	5	35	20	Log-normal	5	35	2	Log-normal	0.5	3.5
Cm	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
Cs	1E-09	Log-normal	1E-09	1E-09	2	Log-normal	0.5	3.5	10	Log-normal	2.5	17.5
Fr	1E-09	Log-normal	1E-09	1E-09	2	Log-normal	0.5	3.5	10	Log-normal	2.5	17.5
H	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09
I	5	Log-normal	1.25	8.75	9	Log-normal	2.25	15.75	1E-09	Log-normal	1E-09	1E-09
K	1E-09	Log-normal	1E-09	1E-09	2	Log-normal	0.5	3.5	10	Log-normal	2.5	17.5
Lu	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
Mo	0.1	Log-normal	0.025	0.175	0.1	Log-normal	0.025	0.175	0.1	Log-normal	0.025	0.175
Nb	1000	Log-normal	250	1750	1000	Log-normal	250	1750	500	Log-normal	125	875
Ni	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
Np	4000	Log-normal	1000	7000	4000	Log-normal	1000	7000	3000	Log-normal	750	5250
Pa	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	500	Log-normal	125	875
Pb	500	Log-normal	125	875	500	Log-normal	125	875	250	Log-normal	62.5	437.5

Element	Young				Middle				Old			
	Best K_d (2,3)	Distribution	Min (2,3)	Max (2,3)	Best K_d (2,3)	Distribution	Min (2,3)	Max (2,3)	Best K_d (2,3)	Distribution	Min (2,3)	Max (2,3)
Pd	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
Po	500	Log-normal	125	875	500	Log-normal	125	875	250	Log-normal	62.5	437.5
Pt	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	500	Log-normal	125	875
Pu	10000	Log-normal	2500	17500	10000	Log-normal	2500	17500	10000	Log-normal	2500	17500
Ra	0.5	Log-normal	0.125	0.875	3	Log-normal	0.75	5.25	20	Log-normal	5	35
Rn	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09	1E-09	Log-normal	1E-09	1E-09
Se	300	Log-normal	75	525	300	Log-normal	75	525	150	Log-normal	37.5	262.5
Sr	0.5	Log-normal	0.125	0.875	3	Log-normal	0.75	5.25	20	Log-normal	5	35
Tc	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750
Th	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	500	Log-normal	125	875
Tl	1	Log-normal	0.25	1.75	1	Log-normal	0.25	1.75	0.1	Log-normal	0.025	0.175
U	2500	Log-normal	625	4375	2500	Log-normal	625	4375	2500	Log-normal	625	4375
Y	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	1000	Log-normal	250	1750
Zr	5000	Log-normal	1250	8750	5000	Log-normal	1250	8750	500	Log-normal	125	875

(1) Grogan et al., 2008, "Distribution of Sorption Coefficients (K_d Values) in the SRS Subsurface Environment", WSRC-STI-2008-00285; extended same method for distributions in sandy soil to concrete K_ds.
(2) Zero values represented as 1E-09 for computational purposes (to avoid divide by zero errors)
(3) All values in mL/g

Table 5. Cellulose Degradation Product Correction Factors for Composite Analysis

Element	Correction Factor	Reference	Analog	Comments [1]
Ac	0.049	Kaplan 2007a [2]	Ce & Eu	
Ag	1.41	Kaplan 2007a [2]	Ni	Soft monovalent
Al	0.049	Kaplan 2007a [2]	Ce & Eu	Hard trivalent
Am	0.049	Kaplan 2007a [2]	Ce & Eu	
At	0.5	Kaplan 2007a [2]	None	
Ba	1.89	Kaplan 2007a [2]	Sr	
Bi	0.049	Kaplan 2007a [2]	Ce & Eu	trivalent cation
C	0.5	Kaplan 2007a [2]	None	
Ca	1.89	Kaplan 2007a [2]	Sr	divalent cation
Cd	1.89	Kaplan 2007a [2]	Sr	divalent cation
Cf	0.049	Kaplan 2007a [2]	Ce & Eu	
Cl	1	Kaplan and Serkiz 2006 [3]	Iodide	
Cm	0.049	Kaplan 2007a [2]	Ce & Eu	
Cs	1.66	Kaplan 2007a [2]	Cs	
Fr	1.66	Kaplan 2007a [2]	Cs	
H	1	Kaplan 2007a [2]	N/A	
I	1	Kaplan and Serkiz 2006 [3]	None	
K	1.66	Kaplan 2007a [2]	Cs	monovalent cation
Lu	0.049	Kaplan 2007a [2]	Ce & Eu	trivalent lanthanide
Mo	1	Kaplan and Serkiz 2006 [3]	Selenate	oxyanion
Nb	1	Kaplan and Serkiz 2006 [3]	Selenate	oxyanion
Ni	1.41	Kaplan 2007a [2]	Ni	
Np	1.66	Kaplan 2007a [2]	Cs	
Pa	1.66	Kaplan 2007a [2]	Cs	
Pb	1.41	Kaplan 2007a [2]	Ni	
Pd	1.41	Kaplan 2007a [2]	Ni	No analog for soft divalent, Ni is closest
Po	1.41	Kaplan 2007a [2]	Ni	
Pt	1.41	Kaplan 2007a [2]	Ni	No analog for soft divalent, Ni is closest
Pu	0.51	Kaplan 2007a [2]	Th	
Ra	1.89	Kaplan 2007a [2]	Sr	
Rn	1	Kaplan 2007a [2]	N/A	
Se (sand)	0.2	Kaplan and Serkiz 2006 [3]	Selenate	
Se (clay)	1	Kaplan and Serkiz 2006 [3]	Selenate	
Sr	1.89	Kaplan 2007a [2]	Sr	
Tc	1	Kaplan and Serkiz 2006 [3]	None	
Th	0.51	Kaplan 2007a [2]	Th	

Element	Correction Factor	Reference	Analog	Comments [1]
Tl	1.66	Kaplan 2007a [2]	Cs	monovalent cation except under strongly reducing conditions
U	1.89	Kaplan 2007a [2]	Sr	
Y	0.049	Kaplan 2007a [2]	Ce & Eu	trivalent cation
Zr	0.08	Kaplan 2007a [2]	Zr	

[1] Comments provide basis for selection of analog for elements not listed in Kaplan (2007a) or Kaplan and Serkiz (2006) based on professional judgment
[2] Correction factor for element or analog given in Table 15 of Kaplan (2007a)
[3] Correction factor for element or analog given in Table 7 of Kaplan and Serkiz (2006)

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