

Table A1. The coal utilization ashes in this study are relatively enriched in rare earth elements, scandium, and yttrium (REYSc) and are from four facilities identified as plants D, I, KSU, and W. The parent coals of the ashes are listed, when known. The samples include bulk coal ashes, ash fractions of the bulk ashes, and five additional fly ash samples collected from plant D in 2002. Samples of the bulk ashes were separated into carbon-rich; magnetic; and +60, +200, and -200 non-magnetic mesh size fractions. The mass percentages of the oversized fractions (+60 mesh) were 9.6%, 0.5%, 0.0%, and 0.4% for plants D, I, KSU, and W, respectively. The quantities of the oversized (+60 mesh) fractions were often too small for leaching and extraction studies. The mass percentages of the other fractions are listed.

CAER Ash ID #	Hower Ash ID #	Sample	Mass Percent Fraction of Total	Parent Coal
75665	93997	Plant D bulk composite pond ash	100	Various, eastern KY
75802	---	Plant D carbon fraction of composite ash	23.1	Various, eastern KY
75803	---	Plant D magnetic fraction of composite ash	4.9	Various, eastern KY
75805	---	Plant D -200 fine non-magnetic fraction of composite ash	52.8	Various, eastern KY
75804	---	Plant D +200 coarse non-magnetic fraction of composite ash	9.6	Various, eastern KY
75920	92997	Plant D fly ash, Unit 1 row 1 ESP bulk, collected in 2002	100	Various, eastern KY
75921	92998	Plant D fly ash, Unit 2 row 1 ESP bulk, collected in 2002	100	Various, eastern KY
75922	92999	Plant D fly ash, Unit 3 mechanical 3-5 bulk, collected in 2002	100	Various, eastern KY
75923	93000	Plant D fly ash, Unit 3 mechanical 3-7 bulk, collected in 2002	100	Various, eastern KY
75924	93003	Plant D fly ash, Unit 4 mechanical 4-5 bulk, collected in 2002	100	Various, eastern KY
73824	93951	Plant I bulk fly ash	100	Fire Clay, eastern KY
74929	---	Plant I carbon fraction	18.2	Fire Clay, eastern KY
74930	---	Plant I magnetic fraction	8.1	Fire Clay, eastern KY
74932	---	Plant I -200 fine non-magnetic fraction	68.6	Fire Clay, eastern KY
74933	---	Plant I +200 coarse non-magnetic fraction	4.7	Fire Clay, eastern KY
74934	93962	KSU bulk stoker ash	100	Various, eastern KY
74935	---	KSU carbon fraction	33.7	Various, eastern KY
74936	---	KSU magnetic fraction	14.8	Various, eastern KY
74937	---	KSU -200 fine non-magnetic fraction	21.9	Various, eastern KY
74938	---	KSU +200 coarse non-magnetic fraction	29.6	Various, eastern KY
73627	93932	Plant W bulk fly ash	100	Fire Clay, eastern KY
74924	---	Plant W carbon fraction	10.1	Fire Clay, eastern KY
74925	---	Plant W magnetic fraction	10.2	Fire Clay, eastern KY
74927	---	Plant W -200 fine non-magnetic fraction	69.1	Fire Clay, eastern KY
74928	---	Plant W +200 coarse non-magnetic fraction	10.2	Fire Clay, eastern KY

Table A2. Detected phases in the ashes of Table A1. The phases were identified with powder X-ray diffraction (XRD). The X-ray diffractograms are shown in Appendix B. The results are qualitative and the minerals are grouped into major, minor and trace categories.

CAER Ash ID #	Hower Ash ID #	Sample	Detected Phases			
			Major	Minor	Trace	Other
75665	93997	Plant D bulk composite pond ash	Quartz	Mullite	Calcite, Hematite?, Magnetite?	+ Amorphous phases
75802	---	Plant D carbon fraction of composite ash	Quartz	Mullite, Hematite?	Magnetite?, Calcite?	+ Amorphous phases
75803	---	Plant D magnetic fraction of composite ash	Magnetite, Quartz, Hematite	Mullite		+ Amorphous phases
75805	---	Plant D -200 fine non-magnetic fraction of composite ash	Quartz	Mullite	Microcline	+ Amorphous phases
75804	---	Plant D +200 coarse non-magnetic fraction of composite ash	Quartz	Mullite	Calcite, Microcline, Na-plagioclase	+ Amorphous phases
75920	92997	Plant D 2002 fly ash Unit 1 row 1 ESP bulk	Quartz	Mullite, Hematite	Magnetite	+ Amorphous phases
75921	92998	Plant D 2002 fly ash Unit 2 row 1 ESP bulk	Quartz	Mullite		+ Amorphous phases
75922	92999	Plant D 2002 fly ash Unit 3 mechanical 3-5 bulk	Quartz	Mullite, Hematite	Magnetite	+ Amorphous phases
75923	93000	Plant D 2002 fly ash Unit 3 mechanical 3-7 bulk	Quartz	Mullite		+ Amorphous phases
75924	93003	Plant D 2002 fly ash Unit 4 mechanical 4-5 bulk	Quartz	Mullite, Hematite	Magnetite, Microcline	+ Amorphous phases
73824	93951	Plant I bulk fly ash	Quartz, Mullite	Hematite, Magnetite, Gypsum		+ Amorphous phases
74929	---	Plant I carbon fraction	Quartz, Mullite	Hematite	Magnetite	+ Amorphous phases
74930	---	Plant I magnetic fraction	Magnetite, Hematite, Quartz	Mullite		+ Amorphous phases
74932	---	Plant I -200 fine non-magnetic fraction	Quartz	Mullite		+ Amorphous phases
74933	---	Plant I +200 coarse non-magnetic fraction	Quartz	Mullite		+ Amorphous phases
93962	---	KSU bulk stoker ash	Mullite, Quartz	Cristobalite, Hematite	Magnetite?	+ Amorphous phases
74934	---	KSU carbon fraction	Mullite	Quartz, Hematite		+ Amorphous phases
74935	---	KSU magnetic fraction	Mullite	Hematite, Magnetite	Quartz, Cristobalite	+ Amorphous phases
74936	---	KSU -200 fine non-magnetic fraction	Mullite	Quartz, Cristobalite		+ Amorphous phases
74937	---	KSU +200 coarse non-magnetic fraction	Mullite	Cristobalite, Quartz		+ Amorphous phases
73627	93932	Plant W bulk fly ash	Quartz	Mullite, Hematite	Magnetite?	+ Amorphous phases
74924	---	Plant W carbon fraction	Quartz	Mullite	Hematite?, Magnetite?	+ Amorphous phases
74925	---	Plant W magnetic fraction	Magnetite, Quartz	Mullite, Hematite	Micas, Kaolinite	+ Amorphous phases
74927	---	Plant W -200 fine non-magnetic fraction	Quartz	Mullite		+ Amorphous phases
74928	---	Plant W +200 coarse non-magnetic fraction	Quartz	Mullite, Hematite		+ Amorphous phases

Table A3. Concentrations of REYSc elements in the solid plant D bulk composite pond ash, its fractions, and 2002 fly ash samples in micrograms of element per gram of sample ($\mu\text{g/g}$). Dashes indicate elements that were not measured and less than values are non-detects.

Sample	CAER Ash ID #	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total Meas. REYSc
Plant D bulk composite pond ash	75665	33	59	69	147	21	161	15	3	20	5	13	<1	12	1	---	---	559
Plant D carbon fraction of composite ash	75802	56	103	102	220	29	232	22	5	29	11	23	9	18	<1	13	3	875
Plant D magnetic fraction of composite ash	75803	28	47	50	93	34	93	13	2	46	4	10	6	8	<1	9	6	449
Plant D -200 (fine) fraction of composite ash	75805	43	38	70	152	19	173	15	3	17	7	13	6	12	<1	7	1	576
Plant D +200 (coarse) fraction of composite ash	75804	23	39	68	138	16	132	12	2	13	5	9	4	8	<1	5	1	475
Plant D 2002 fly ash Unit 1 row 1 ESP	75920	40	102	111	209	26	219	20	5	24	5	17	<1	15	19	10	2	824
Plant D 2002 fly ash Unit 2 row 1 ESP	75921	37	92	103	192	23	218	18	5	21	5	16	<1	14	20	9	2	775
Plant D 2002 fly ash Unit 3 mechanical 3-5	75922	34	85	97	181	22	198	17	4	21	5	14	<1	13	18	8	2	719
Plant D 2002 fly ash Unit 3 mechanical 3-7	75923	35	92	105	196	24	209	18	5	23	5	15	<1	14	19	9	2	771
Plant D 2002 fly ash Unit 4 mechanical 4-5	75924	37	99	107	202	24	215	18	5	23	5	17	<1	15	20	10	2	799

Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total Meas. REYSc
Maximum value ($\mu\text{g/g}$)	56	103	102	220	34	232	22	5	46	11	23	9	18	20	13	6	875
Minimum value ($\mu\text{g/g}$)	23	38	50	93	16	93	12	2	13	4	9	<1	8	<1	5	1	449
% Change non-magnetic fine vs coarse	87.0	-2.6	2.9	10.1	18.8	31.1	25.0	50.0	30.8	40.0	44.4	---	50.0	---	40.0	0.0	21.3
% Change non-magnetic fine vs magnetic	53.6	-19.1	40.0	63.4	-44.1	86.0	15.4	50.0	-63.0	75.0	30.0	---	50.0	---	-22.2	-83.3	28.3

Table A4. Concentrations of REYSc elements in the solid plant I bulk ash and its fractions in micrograms of element per gram of sample ($\mu\text{g/g}$).

Sample	CAER Ash ID #	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Plant I bulk fly ash	73824	38	86	110	212	36	111	22	4	20	3	16	5	13	3	9	1.3	658
Plant I carbon fraction of fly ash	74929	49	104	106	207	38	122	25	5	24	4	21	6	17	4	12	1.7	745
Plant I magnetic fraction of fly ash	74930	32	80	86	161	80	83	32	3	19	5	20	2	11	2	10	5.7	632
Plant I -200 non-magnetic fraction of fly ash	74932	36	69	92	191	25	109	20	3	19	2	15	5	13	3	8	0.3	610
Plant I +200 non-magnetic fraction of fly ash	74933	20	40	65	140	18	77	14	2	13	1	10	3	9	2	5	0.01	420

Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total Meas. REYSc
Maximum value ($\mu\text{g/g}$)	49	104	110	212	80	122	32	5	24	5	21	6	17	4	12	5.7	745
Minimum value ($\mu\text{g/g}$)	20	40	65	140	18	77	14	2	13	1	10	2	9	2	5	0.01	420
% Change non-magnetic fine vs coarse	80.0	72.3	41.4	36.4	38.7	41.3	35.8	49.9	44.2	74.8	52.6	54.2	46.9	74.5	66.6	2208	45.4
% Change non-magnetic fine vs magnetic	14.5	-13.7	6.5	18.5	-68.2	30.5	-38.5	-1.4	-2.9	-51.1	-26.4	144	22.0	12.2	20.9	-94.1	-3.5

Table A5. Concentrations of REYSc elements in the solid KSU bulk ash and its fractions in micrograms of element per gram of sample ($\mu\text{g/g}$).

Sample	Ash ID #	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
KSU bulk stoker ash	93962	47	214	174	398	44	171	35	5	40	6	35	7	22	3	19	2.9	1222
KSU carbon fraction of stoker ash	74934	52	180	223	428	56	235	46	6	40	4	33	10	24	5	19	2.7	1362
KSU magnetic fraction of stoker ash	74935	59	205	212	403	70	229	49	6	42	6	37	10	25	6	22	4.6	1386
KSU -200 non-magnetic fraction of stoker ash	74936	45	152	187	380	46	217	40	5	35	4	28	9	21	5	16	1.9	1192
KSU +200 non-magnetic fraction of stoker ash	74937	51	155	156	333	44	219	38	5	35	4	28	10	23	5	18	2.2	1127

Parameter																		
Maximum value ($\mu\text{g/g}$)		59	214	223	428	70	235	49	6	42	6	37	10	25	6	22	5	1386
Minimum value ($\mu\text{g/g}$)		47	155	156	333	44	171	35	5	35	4	28	7	22	3	18	2	1127
% Change non-magnetic fine vs coarse		-12.2	-2.1	20.0	14.1	3.6	-1.1	4.9	0.9	1.5	-15.4	-0.4	-2.7	-5.3	-13.4	-10.2	-12.6	5.8
% Change non-magnetic fine vs magnetic		-23.9	-26.0	-11.5	-5.6	-35.0	-5.4	-18.0	-19.9	-16.5	-35.5	-26.3	-8.7	-15.0	-18.7	-25.2	-58.4	-14.0

Table A6. Concentrations of REYSc elements in the solid plant W bulk ash and its fractions in micrograms of element per gram of sample ($\mu\text{g/g}$).

Sample	CAER Ash ID #	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Plant W bulk fly ash	73627	42	108	108	212	24	88	19	4	19	3	17	4	10	1	9	1.3	669
Plant W carbon fraction of fly ash	74924	55	116	125	228	47	114	25	6	28	4	23	7	18	4	12	1.5	813
Plant W magnetic fraction of fly ash	74925	31	65	72	129	78	62	27	3	17	4	18	2	9	2	9	5.2	533
Plant W -200 non-magnetic fraction of fly ash	74927	37	64	80	161	30	81	16	3	17	2	13	5	12	3	7	0.4	531
Plant W +200 non-magnetic fraction of fly ash	74928	22	30	44	101	19	53	10	2	10	1	8	3	7	1	4	0.1	316

Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Maximum value ($\mu\text{g/g}$)	55	116	125	228	78	114	27	6	28	4	23	7	18	4	12	5.2	813
Minimum value ($\mu\text{g/g}$)	22	30	44	101	19	53	10	2	10	1	8	2	7	1	4	0.1	316
% Change non-magnetic fine vs coarse	64.9	115	80.6	59.3	59.5	51.8	58.0	66.6	67.8	50.6	73.2	63.6	59.0	84.3	79.6	633	67.8
% Change non-magnetic fine vs magnetic	16.9	-0.8	12.1	24.6	-62.0	29.5	41.6	4.4	1.1	-53.9	-25.1	199	31.1	28.9	-18.6	-92.0	-0.4

Table A7. Deionized water (DI) batch leaching procedures for plants D, I, KSU, and W bulk ashes and their acid blanks. Nitric acid was added to the DI water leachates after filtering as a preservative until analysis.

Leachate ID	CAER Ash ID #	Hower Ash ID #	Sample	Mass Sample, grams	Mass DI water, grams	Mass 69.4% Nitric Acid during Leaching, grams	Liquid-to-Solid Ratio	Leaching Time (hours)	Filter, microns (μm)
C	---	---	DI water, nitric acid, filtered blank for the plant D bulk ash DI leachate	0	20.1548	1.3885	---	48	0.45
K	---	---	DI water, nitric acid, filtered blank for plants I, KSU, and W bulk ash DI leachates	0	20.2398	1.3826	---	48	0.45
D	75665	93997	Plant D composite bulk DI leachate	100.4	400.0	0	3.98	48	0.45
22		93951	Plant I bulk fly ash DI leachate	100.0	400.0	0	4.00	48	0.45
23		93962	KSU bulk stoker ash DI leachate	100.1	392.2	0	3.92	48	0.45
24		93932	Plant W bulk fly ash DI leachate	100.1	403.1	0	4.03	48	0.45
25		93932	Plant W bulk fly ash DI leachate, duplicate	100.0	400.2	0	4.00	48	0.45

Table A8. Nitric acid leaching and extraction procedures for the ashes listed in Table A1. The samples were leached in 4.2-4.9 wt% nitric acid for 48 hours and then filtered at 0.45 μm . The text and shaded gray rows describe the heated extractions, which were developed from a modification of the ASTM D6357-04 procedure (ASTM, 2010). Only the final mass of the nitric acid in the extractions is shown below and not the mass of nitric acid that boiled away. The liquid-to-solid ratios for the two extractions were adjusted to account for loss from evaporation during the final heating step. Nitric acid blanks and duplicates were produced for each of the four groups of samples (1-21, A-B, E-J, and L-P).

Leachate ID #	CAER Ash ID #	Howar Ash ID #	Sample	Mass Sample, g	Mass DI water, g	Mass 69-70% Nitric Acid, g	Liquid-to-Solid Ratio
2	---	---	DI water, nitric acid, filtered blank for I, KSU and W samples 1-21	0	20.5745	1.4034	---
C	---	---	DI water, nitric acid, filtered blank for plant D samples A-B	0	20.1548	1.3885	---
K	---	---	DI water, nitric acid, filtered blank for plant D samples E-J	0	20.2398	1.3826	---
Q	---	---	DI water, nitric acid, filtered blank for plant D samples L-P	0	20.1314	1.3941	---
A	75665	93997	Plant D composite bulk fly ash nitric acid leachate	0.3593	21.4439	1.3910	64
B	75665	93997	Plant D composite bulk fly ash nitric acid leachate, duplicate	0.2277	20.3670	1.3871	96
E	75920	92997	Plant D 2002 fly ash Unit 1 row 1 ESP nitric acid leachate	0.2227	20.1114	1.3974	97
F	75920	92997	Plant D 2002 fly ash Unit 1 row 1 ESP nitric acid leachate, duplicate	0.3127	20.9510	1.3973	71
G	75922	92999	Plant D 2002 fly ash Unit 3 mechanical 3-5 nitric acid leachate	0.2911	20.1455	1.3169	74
H	75923	93000	Plant D 2002 fly ash Unit 3 mechanical 3-7 nitric acid leachate	0.2844	20.2221	1.3854	76
I	75924	93003	Plant D 2002 fly ash Unit 4 mechanical 4-5 nitric acid leachate	0.3173	20.9910	1.4037	71
J	75921	92998	Plant D 2002 fly ash ESP Unit 2 row 1 nitric acid leachate	0.2489	20.8548	1.3971	89
L	75802		Plant D carbon fraction nitric acid leachate	0.4628	20.3218	1.3931	46
M	75803		Plant D magnetic fraction nitric acid leachate	0.4269	21.0380	1.4072	53
N	75805		Plant D -200 non-magnetic fraction nitric acid leachate	0.4603	20.3629	1.3967	47
O	75804		Plant D +200 non-magnetic fraction nitric acid leachate	0.4602	20.2558	1.4084	47
P	75804		Plant D +200 non-magnetic fraction nitric acid leachate, duplicate	0.3686	20.0394	1.3967	58
4		93951	Plant I bulk fly ash nitric acid leachate	0.4669	20.3706	1.3949	47
5	74932		Plant I -200 non-magnetic fraction nitric acid leachate	0.3132	20.1944	1.3818	69
6	74933		Plant I +200 non-magnetic fraction nitric acid leachate	0.2381	20.0594	1.3947	90
1	74933		Plant I +200 non-magnetic fraction heated nitric acid extraction	0.2522	20.8616	1.0210	56
7	74929		Plant I carbon fraction acid nitric leachate	0.2132	19.9714	1.3976	100
8	74930		Plant I magnetic fraction acid nitric leachate	0.2783	20.2135	1.4110	78
9	74930		Plant I magnetic fraction acid nitric leachate, duplicate	0.3219	22.0910	1.4006	73
10		93962	KSU bulk stoker ash nitric acid leachate	0.3982	20.5773	1.4021	55
11		93962	KSU bulk stoker ash nitric acid leachate, duplicate	0.4704	20.4204	1.4132	46
12	74936		KSU -200 non-magnetic fraction nitric acid leachate	0.2267	20.4450	1.4003	96
13	74934		KSU carbon fraction nitric acid leachate	0.2427	20.0133	1.4041	88
14	74937		KSU +200 non-magnetic fraction nitric acid leachate	0.2323	20.2919	1.3959	93
15	74935		KSU magnetic fraction nitric acid leachate	0.3090	20.8650	1.4081	72
16		93932	Plant W bulk fly ash nitric acid leachate	0.3757	20.7510	1.4109	59
17	74928		Plant W +200 non-magnetic fraction nitric acid leachate	0.2363	21.4714	1.4006	97
18	74928		Plant W +200 non-magnetic fraction nitric acid leachate, duplicate	0.2518	20.4906	1.4093	87
3	74928		Plant W +200 non-magnetic fraction heated nitric acid extraction	0.4170	21.3641	1.5501	41
19	74927		Plant W -200 non-magnetic fraction nitric acid leachate	0.3524	20.5626	1.4109	62
20	74924		Plant W carbon nitric acid leachate	0.3096	20.0061	1.4139	69
21	74925		Plant W magnetic nitric acid leachate	0.3010	20.5817	1.3988	73

Table A9. Concentrations in milligrams per liter (mg/L) of potentially toxic elements in the DI water leachates and comparisons with the US federal limits in mg/L for the toxicity characteristic of hazardousness in liquid wastes (40 *Code of Federal Regulations* [CFR] 261.24). Dashes indicate elements that were not measured and less than values are non-detects. The barium values for the blanks (shown in italics and shaded) are unusually high and were confirmed by a second laboratory. Both sets of values are listed with the value from the second laboratory following the first. The barium concentrations of the samples are those reported by the two laboratories and do **not** include subtraction of the blank values.

Sample	Arsenic	Barium	Cadmium	Chromium	Lead	Mercury	Selenium
U.S. federal limit for toxicity	5.0	100.0	1.0	5.0	5.0	0.2	1.0
DI, nitric acid, filtered blank C	<0.001	<i>0.311</i>	<0.001	---	<0.001	<0.001	<0.001
DI, nitric acid, filtered blank K	<0.001	<i>0.419;</i> <i>0.516</i>	<0.001	0.001	<0.001	<0.001	<0.001
Plant D composite bulk	0.196	0.062	<0.001	---	<0.001	<0.001	0.380
Plant I bulk fly ash	0.460	0.022; 0.107	<0.001	0.019	<0.001	<0.001	0.990
KSU bulk stoker ash	<0.001	<0.001; 0.006	<0.001	<0.001	<0.001	<0.001	<0.001
Plant W bulk fly ash	<0.001	0.539; 0.614	<0.001	0.279	<0.001	<0.001	0.485
Plant W bulk fly ash, duplicate	0.071	0.468; 0.578	<0.001	0.273	<0.001	<0.001	0.532

Table A10. Detected REYSc concentrations in mg/L and the pre-filtered and post-filtered pH results for the DI leachates of the plants D, I, KSU and W bulk ashes and the REYSc results for their acid blanks. The detection limit of Ho for the second laboratory was 0.00002 mg/L. The detection limits of the other elements were 0.001 mg/L. The results from the second laboratory are listed after the first. Sc, Y, Ce, Nd, Sm, Eu, Gd, Dy, Tm, Yb, and Lu were not detected in any of the DI water leachates and their acid blanks. The percent differences of the pH values of the duplicated plant W DI water leachates are listed. To eliminate any possible effects from differences in the liquid-to-solid ratios, the percent differences in the detected REEs of the duplicated plant W leachates are listed in Table A11.

Leachate ID	CAER Ash ID #	Hower Ash ID #	Sample	Pre-filter pH	Post-filter pH	La	Pr	Tb	Ho	Er
C	---	---	DI water, nitric acid, filtered blank for the plant D bulk fly ash DI leachate	---	---	<0.001	<0.001	<0.001	0.002; 0.00002	<0.001
K	---	---	DI water, nitric acid, filtered blank for plants I, KSU and W bulk ash DI leachates	---	---	<0.001	<0.001	<0.001	0.001	<0.001
D	75665	93997	Plant D bulk composite pond ash DI leachate	8.34	8.26	0.039	<0.001	<0.001	0.019; <0.00002	<0.001
22		93951	Plant I bulk fly ash DI leachate	8.21	8.26	0.124	0.023	<0.001	0.067	<0.001
23		93962	KSU bulk stoker ash DI leachate	9.14	9.25	0.017	<0.001	0.001	0.004	<0.001
24		93932	Plant W bulk fly ash DI leachate	11.0	11.0	0.136	0.030	<0.001	0.071	0.002
25		93932	Plant W bulk fly ash DI leachate, duplicate	10.9	10.9	0.139	0.035	<0.001	0.064	<0.001
23		93932	% Difference duplicates plant W bulk fly ash DI leachates	0.9	0.9	For REEs, see Table A11				

Table A11. Micrograms of REEs leached per gram of ash ($\mu\text{g/g}$) for plants D, I, KSU and W bulk ash DI water leachates. The results were obtained by multiplying the mg/L concentrations of the leachates (Table A10) by their liquid-to-solid ratios (Table A7). Sc, Y, Ce, Nd, Sm, Eu, Gd, Dy, Tm, Yb, and Lu were not detected in any of the DI water leachates. For Ho in sample D, <0.02 mg/L was used in the calculations. The percent differences in the detected REEs of the duplicated plant W leachates are listed.

Leachate ID	CAER Ash ID #	Ash Hower ID #	Sample	La	Pr	Tb	Ho	Er
D	75665	93997	Plant D bulk composite pond ash DI leachate	0.155	<0.004	<0.004	<0.08	<0.004
22		93951	Plant I bulk fly ash DI leachate	0.496	0.092	<0.004	0.268	<0.004
23		93962	KSU bulk stoker ash DI leachate	0.067	<0.004	0.004	0.016	<0.004
24		93932	Plant W bulk fly ash DI leachate	0.548	0.121	<0.004	0.286	0.008
25		93932	Plant W bulk fly ash DI leachate, duplicate	0.556	0.140	<0.004	0.256	<0.004
24, 25		93932	% Difference duplicates plant W bulk fly ash DI leachates	1.6	14.8	---	11.0	---

Table A12. Percentages of REEs leached from the D, I, KSU, and W bulk ashes by DI water. The results were obtained by dividing the leached concentrations in Table A11 by the REE concentrations in the ashes (Tables A3-A6). Ho was not detected in the Plant D composite ash. Sc, Y, Ce, Nd, Sm, Eu, Gd, Dy, Tm, Yb, and Lu were not detected in any of the DI water leachates and their percentages would be <0.4%.

Leachate ID	CAER Ash ID #	Hower Ash ID #	Sample	La %	Pr %	Tb %	Ho %	Er %
D	75665	93997	Plant D bulk composite pond ash DI leachate	0.2	<0.02	<0.1	---	<0.03
22		93951	Plant I bulk fly ash DI leachate	0.5	0.3	<0.1	5.2	<0.03
23		93962	KSU bulk stoker ash DI leachate	0.04	<0.01	0.07	0.2	<0.02
24		93932	Plant W bulk fly ash DI leachate	0.5	0.5	<0.2	8.1	0.08
25		93932	Plant W bulk fly ash DI leachate, duplicate	0.5	0.6	<0.2	7.2	<0.04

Table A13. Concentrations in mg/L of REYSc in the nitric acid leachates for the plant D samples shown in Table A1. Duplicate analyses from a second laboratory are listed below the first. Blanks C, K, and Q were prepared at the same time as the A-B, E-J, and L-P plant D leachates, respectively.

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Sample C; DI water, nitric acid, filtered blank for Plant D samples A-B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001; 0.0002	<0.001	<0.001	<0.001	<0.001	<0.001	0.002; 0.00002	<0.001	<0.001	<0.001	<0.001
Sample K; DI water, nitric acid, filtered blank for Plant D samples E-J	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001
Sample Q; DI water, nitric acid, filtered blank for Plant D samples L-P	<0.001	0.026	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sample A; Plant D composite bulk fly ash nitric acid leachate	0.091	0.216	0.280	0.41; 0.530	0.055	0.334; 0.280	0.056	0.013	0.067	0.012	0.058	0.049; 0.0148	0.036	0.013	0.029	0.005
Sample B; Plant D composite bulk fly ash nitric acid leachate, duplicate	0.058	0.120	0.175	0.23; 0.310	0.035	0.207; 0.166	0.032	0.008	0.042	0.009	0.037	0.032; 0.00878	0.023	0.006	0.019	0.003
Sample E; Plant D 2002 fly ash Unit 1 row 1 ESP nitric acid leachate	0.073	0.183	0.232	0.377	0.051	0.263	0.048	0.010	0.055	0.008	0.048	0.033	0.028	0.010	0.023	0.002
Sample F; Plant D 2002 fly ash Unit 1 row 1 ESP nitric acid leachate, duplicate	0.096	0.255	0.293	0.506	0.063	0.359	0.073	0.013	0.074	0.011	0.064	0.042	0.039	0.014	0.031	0.004
Sample G; Plant D 2002 fly ash Unit 3 mechanical 3-5 nitric acid leachate	0.050	0.117	0.176	0.262	0.031	0.194	0.036	0.006	0.042	0.008	0.034	0.032	0.019	0.007	0.015	0.002
Sample H; Plant D 2002 fly ash Unit 3 mechanical 3-7 nitric acid leachate	0.052	0.127	0.194	0.272	0.039	0.196	0.039	0.007	0.044	0.007	0.037	0.031	0.022	0.007	0.016	0.002
Sample I; Plant D 2002 fly ash Unit 4 mechanical 4-5 nitric acid leachate	0.063	0.163	0.208	0.313	0.045	0.234	0.043	0.008	0.051	0.010	0.045	0.038	0.027	0.010	0.020	0.002
Sample J; Plant D 2002 fly ash ESP Unit 2 row 1 nitric acid leachate	0.056	0.119	0.163	0.242	0.035	0.190	0.033	0.007	0.043	0.007	0.036	0.023	0.021	0.008	0.016	0.002
Sample L; Plant D carbon fraction nitric acid leachate	0.158	0.594	0.469	0.826	0.108	0.646	0.096	0.028	0.112	0.022	0.102	0.007	0.063	0.027	0.054	0.008
Sample M; Plant D magnetic fraction nitric acid leachate	0.066	0.289	0.239	0.337	0.046	0.273	0.045	0.014	0.066	0.012	0.048	0.004	0.026	0.009	0.026	0.006
Sample N; Plant D -200 non-magnetic fraction nitric acid leachate	0.132	0.504	0.409	0.666	0.079	0.509	0.082	0.023	0.095	0.017	0.085	0.006	0.053	0.020	0.043	0.007
Sample O; Plant D +200 non-magnetic fraction nitric acid leachate, duplicate	0.035	0.167	0.238	0.270	0.028	0.201	0.029	0.007	0.033	0.005	0.025	<0.001	0.015	0.005	0.013	0.002
Sample P; Plant D +200 non-magnetic fraction nitric acid leachate	0.028	0.139	0.201	0.217	0.026	0.160	0.022	0.002	0.029	<0.001	0.018	<0.001	0.011	0.004	0.011	0.002

Table A14. Concentrations in mg/L of REYSc in the nitric acid leachates and extraction for the plant I samples shown in Table A1. The shaded gray sample is the heated extraction results from the modified ASTM D6357-04 procedure (ASTM, 2010). Blank 2 was prepared at the same time as the leachates.

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Sample #2; DI water, nitric acid, filtered blank for samples 1-21	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sample #4; Plant I bulk fly ash nitric acid leachate	0.100	0.310	0.342	0.536	0.092	0.419	0.068	0.014	0.080	0.012	0.066	0.005	0.043	0.001	0.034	0.006
Sample #5; Plant I -200 non-magnetic fraction nitric acid leachate	0.055	0.184	0.194	0.313	0.046	0.249	0.041	0.008	0.047	0.008	0.039	0.003	0.024	<0.001	0.019	0.003
Sample #6; Plant I +200 non-magnetic fraction nitric acid leachate	0.015	0.053	0.071	0.107	0.005	0.084	0.014	0.003	0.016	0.001	0.011	<0.001	0.008	<0.001	0.006	0.001
Sample #1; Plant I +200 non-magnetic fraction heated nitric acid extraction	0.039	0.112	0.164	0.278	0.043	0.197	0.030	0.005	0.039	0.005	0.025	0.001	0.015	0.001	0.012	0.003
Sample #7; Plant I carbon fraction acid nitric leachate	0.099	0.274	0.296	0.503	0.087	0.383	0.060	0.013	0.068	0.012	0.059	0.030	0.038	0.002	0.032	0.005
Sample #8; Plant I magnetic fraction acid nitric leachate	0.037	0.156	0.157	0.232	0.037	0.183	0.030	0.007	0.044	0.007	0.031	<0.001	0.020	<0.001	0.017	0.004
Sample #9; Plant I magnetic fraction acid nitric leachate, duplicate	0.038	0.164	0.167	0.239	0.044	0.200	0.030	0.007	0.044	0.006	0.033	0.002	0.022	<0.001	0.018	0.004

Table A15. Concentrations in mg/L of REYSc in the nitric acid leachates for the KSU samples shown in Table A1. Blank 2 was prepared at the same time as the leachates.

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Sample #2; DI water, nitric acid, filtered blank for samples 1-21	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sample #10; KSU bulk stoker ash nitric acid leachate	0.011	0.059	0.095	0.133	0.021	0.086	0.015	0.002	0.030	0.002	0.011	<0.001	0.008	<0.001	0.007	0.003
Sample #11; KSU bulk stoker ash nitric acid leachate, duplicate	0.014	0.073	0.119	0.174	0.030	0.114	0.017	0.002	0.036	0.004	0.014	<0.001	0.010	<0.001	0.009	0.004
Sample #12; KSU -200 non-magnetic fraction nitric acid leachate	0.012	0.079	0.116	0.172	0.020	0.117	0.019	0.002	0.022	0.003	0.016	<0.001	0.011	<0.001	0.009	0.002
Sample #13; KSU carbon fraction nitric acid leachate	0.007	0.038	0.062	0.105	0.006	0.067	0.010	0.001	0.014	<0.001	0.008	<0.001	0.005	<0.001	0.004	0.001
Sample #14; KSU +200 non-magnetic fraction nitric acid leachate	0.004	0.018	0.041	0.041	<0.001	0.031	0.006	<0.001	0.005	<0.001	0.003	<0.001	0.004	<0.001	0.002	<0.001
Sample #15; KSU magnetic fraction nitric acid leachate	0.009	0.048	0.062	0.087	0.008	0.062	0.011	0.002	0.020	0.002	0.010	<0.001	0.007	<0.001	0.006	0.002

Table A16. Concentrations in mg/L of REYSc in the nitric acid leachates and extraction for the plant W samples shown in Table A1. The shaded gray sample is the heated extraction results from the modified ASTM D6357-04 procedure (ASTM, 2010). Blank 2 was prepared at the same time as the leachates.

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
Sample #2: DI water, nitric acid, filtered blank for samples 1-21	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Sample #16: Plant W bulk fly ash nitric acid leachate	0.121	0.324	0.423	0.569	0.108	0.491	0.074	0.019	0.095	0.019	0.070	0.003	0.047	<0.001	0.038	0.003
Sample #17: Plant W +200 non-magnetic fraction nitric acid leachate	0.024	0.081	0.145	0.134	0.014	0.124	0.018	0.005	0.027	0.003	0.018	<0.001	0.011	<0.001	0.008	0.002
Sample #18: Plant W +200 non-magnetic fraction nitric acid leachate, duplicate	0.026	0.090	0.160	0.157	0.022	0.143	0.025	0.005	0.031	0.003	0.021	<0.001	0.012	<0.001	0.009	0.002
Sample #3: Plant W +200 non-magnetic fraction heated nitric acid extraction	0.057	0.191	0.297	0.356	0.073	0.288	0.051	0.012	0.067	0.012	0.044	<0.001	0.026	<0.001	0.020	0.006
Sample #19: Plant W -200 non-magnetic fraction nitric acid leachate	0.126	0.330	0.490	0.580	0.107	0.500	0.070	0.019	0.095	0.019	0.074	0.004	0.049	0.002	0.039	0.008
Sample #20: Plant W carbon fraction nitric acid leachate	0.149	0.384	0.490	0.753	0.054	0.601	0.095	0.023	0.108	0.019	0.086	0.004	0.055	0.002	0.047	0.008
Sample #21: Plant W magnetic fraction nitric acid leachate	0.051	0.175	0.249	0.281	0.054	0.253	0.040	0.009	0.055	0.008	0.040	0.001	0.027	<0.001	0.022	0.004

Table A17. Micrograms of REYSc nitric acid leached per gram of the plant D samples ($\mu\text{g/g}$) based on the mg/L concentrations (Table A13) and the liquid-to-solid ratios of the nitric acid leachates (Table A8). Duplicate results from a second laboratory are listed below the first.

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Sample A: Plant D composite ash nitric acid leachate	5.78	13.7	17.8	26.1; 33.7	3.50	21.2; 17.8	3.56	0.826	4.26	0.763	3.69	3.11; 0.94	2.29	0.826	1.84	0.318	110; 115
Sample B: Plant D composite ash nitric acid leachate, duplicate	5.54	11.5	16.7	22.0; 29.6	3.34	19.8; 15.9	3.06	0.764	4.01	0.860	3.53	3.06; 0.84	2.20	0.573	1.82	0.287	99.0; 104
Sample E: Plant D fly ash Unit 1 row 1 ESP nitric acid leachate	7.05	17.7	22.4	36.4	4.93	25.4	4.64	0.966	5.31	0.773	4.64	3.19	2.70	0.966	2.22	0.193	139
Sample F: Plant D fly ash Unit 1 row 1 ESP nitric acid leachate, duplicate	6.86	18.2	20.9	36.2	4.50	25.7	5.22	0.929	5.29	0.786	4.57	3.00	2.79	1.00	2.22	0.286	138
Sample G: Plant D fly ash Unit 3 mechanical 3-5 nitric acid leachate	3.69	8.63	13.0	19.3	2.29	14.3	2.65	0.442	3.10	0.590	2.51	2.36	1.40	0.516	1.11	0.147	76.0
Sample H: Plant D fly ash Unit 3 mechanical 3-7 nitric acid leachate	3.95	9.65	14.7	20.7	2.96	14.9	2.96	0.532	3.34	0.532	2.81	2.36	1.67	0.532	1.22	0.152	83.0
Sample I: Plant D fly ash Unit 4 mechanical 4-5 nitric acid leachate	4.45	11.5	14.7	22.1	3.18	16.5	3.03	0.565	3.60	0.706	3.18	2.68	1.91	0.706	1.41	0.141	90.3
Sample J: Plant D fly ash ESP Unit 2 row 1 nitric acid leachate	5.01	10.6	14.6	21.6	3.13	17.0	2.95	0.626	3.84	0.626	3.22	2.06	1.88	0.715	1.43	0.179	95.1
Sample L: Plant D carbon fraction nitric acid leachate	7.30	27.5	21.7	38.2	4.99	29.9	4.44	1.29	5.18	1.02	4.71	0.324	2.91	1.25	2.50	0.370	153
Sample M: Plant D magnetic fraction nitric acid leachate	3.47	15.2	12.6	17.7	2.42	14.4	2.37	0.736	3.47	0.631	2.52	0.210	1.37	0.473	1.37	0.315	79.2
Sample N: Plant D -200 non-magnetic fraction nitric acid leachate	6.24	23.8	19.3	31.5	3.73	24.1	3.88	1.09	4.49	0.804	4.02	0.284	2.51	0.945	2.03	0.331	129
Sample O: Plant D +200 non-magnetic fraction nitric acid leachate	1.65	7.86	11.2	12.7	1.32	9.46	1.37	0.330	1.55	0.235	1.18	<0.047	0.706	0.235	0.612	0.094	50.5
Sample P: Plant D +200 non-magnetic fraction nitric acid leachate, duplicate	1.63	8.08	11.7	12.6	1.51	9.30	1.28	0.116	1.69	<0.058	1.05	<0.058	0.640	0.233	0.640	0.116	50.6
Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Maximum A-B composite pond ash value ($\mu\text{g/g}$)	5.78	13.7	17.8	33.7	3.50	21.2	3.56	0.826	4.26	0.860	3.69	3.11	2.29	0.826	1.84	0.318	115
Minimum A-B composite pond ash value ($\mu\text{g/g}$)	5.54	11.5	16.7	22.0	3.34	15.9	3.06	0.764	4.01	0.763	3.53	0.84	2.20	0.573	1.82	0.287	99.0
% Difference nitric acid A-B composite duplicates	4.3	18.0	6.2	42.1	4.4	28.9	15.2	7.8	5.9	12.0	4.2	115	4.0	36.2	1.5	10.3	10.2
Maximum E-F unit 1 row 1 ash value ($\mu\text{g/g}$)	7.05	18.22	22.41	36.41	4.93	25.66	5.22	0.97	5.31	0.79	4.64	3.19	2.79	1.00	2.22	0.29	139
Minimum E-F unit 1 row 1 Ash Value ($\mu\text{g/g}$)	6.86	17.67	20.94	36.16	4.50	25.40	4.64	0.93	5.29	0.77	4.57	3.00	2.70	0.97	2.22	0.19	138
% Difference nitric acid E-F duplicates	2.7	3.1	6.8	0.7	9.0	1.0	11.8	3.9	0.4	1.7	1.3	6.0	3.0	3.5	0.3	38.7	0.7
Maximum O-P +200 non-magnetic ($\mu\text{g/g}$)	1.65	8.08	11.7	12.7	1.51	9.46	1.37	0.330	1.69	---	1.18	---	0.706	0.235	0.64	0.116	51
Minimum O-P +200 non-magnetic ($\mu\text{g/g}$)	1.63	7.86	11.2	12.6	1.32	9.30	1.28	0.116	1.55	---	1.05	---	0.640	0.233	0.61	0.094	51
% Difference nitric acid O-P duplicates	1.2	2.8	4.2	0.7	13.7	1.7	6.49	95.6	8.2	---	11.7	---	9.9	1.2	4.4	21.1	0.2
% Change non-magnetic fine vs average coarse	281	199	68.9	149	164	156	193	388	177	---	261	---	272	304	225	214	155
% Change non-magnetic fine vs magnetic	79.8	56.8	53.9	77.7	54.4	67.6	63.8	47.7	29.4	27.4	59.2	34.9	83.3	100	48.7	4.9	63.0

Table A18. Micrograms of REYSc extracted or leached per gram of the plant I samples ($\mu\text{g/g}$) based on the mg/L concentrations (Table A14) and the liquid-to-solid ratios of the nitric acid leachates/extractions (Table A8). The shaded gray sample is an extraction result obtained from a modification of the ASTM D6357-04 procedure (ASTM, 2010).

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Sample #4: Plant I bulk fly ash nitric acid leachate	4.66	14.5	15.9	25.0	4.29	19.5	3.17	0.653	3.73	0.559	3.08	0.233	2.00	0.047	1.58	0.280	99.2
Sample #5: Plant I -200 non-magnetic fraction nitric acid leachate	3.79	12.7	13.4	21.6	3.17	17.2	2.82	0.551	3.24	0.551	2.69	0.207	1.65	<0.069	1.31	0.207	84.9
Sample #6: Plant I +200 non-magnetic fraction nitric acid leachate	1.35	4.78	6.40	9.64	0.451	7.57	1.26	0.270	1.44	0.090	0.991	<0.090	0.721	<0.090	0.541	0.090	35.6
Sample #1: Plant I +200 non-magnetic fraction heated nitric acid extraction	2.18	6.27	9.18	15.6	2.41	11.0	1.68	0.280	2.18	0.280	1.40	0.056	0.840	0.0560	0.672	0.168	54.3
Sample #7 Plant I carbon fraction acid nitric leachate	9.92	27.5	29.7	50.4	8.72	38.4	6.01	1.30	6.82	1.20	5.91	3.01	3.81	0.200	3.21	0.501	197
Sample #8 Plant I magnetic fraction acid nitric leachate	2.87	12.1	12.2	18.0	2.87	14.2	2.33	0.544	3.42	0.544	2.41	<0.078	1.55	<0.078	1.32	0.311	74.7
Sample #9: Plant I magnetic fraction acid nitric leachate, duplicate	2.77	12.0	12.2	17.4	3.21	14.6	2.19	0.511	3.21	0.438	2.41	0.146	1.61	<0.073	1.31	0.292	74.3

Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Maximum value ($\mu\text{g/g}$)	9.92	27.5	29.7	50.4	8.72	38.4	6.01	1.30	6.82	1.20	5.91	3.01	3.81	0.200	3.21	0.501	197
Minimum value ($\mu\text{g/g}$)	1.35	4.78	6.40	9.64	0.451	7.57	1.26	0.270	1.44	0.090	0.991	---	0.721	---	0.541	0.090	35.6
% Difference magnetic duplicates	3.6	1.3	0.1	3.3	11.0	2.6	6.3	6.3	6.3	21.6	0.0	---	3.3	---	0.6	6.3	0.6
% Change hot vs cold +200 mesh (coarse)	61.6	31.3	43.6	61.5	435	45.8	33.2	3.6	51.5	211	41.3	---	16.5	---	24.3	86.5	52.5
% Change non-magnetic fine vs ambient coarse	180	165	109	124	603	127	124	104	125	512	171	---	129	---	142	129	139
% Change non-magnetic fine vs average magnetic	34.2	5.2	9.6	21.6	4.1	19.1	25.0	4.5	-2.3	12.3	11.5	---	4.7	---	-0.6	-31.4	14.0

Table A19. Micrograms of REYSc leached per gram of the KSU samples ($\mu\text{g/g}$) based on the mg/L concentrations (Table A15) and the liquid-to-solid ratios of the nitric acid leachates/extractions (Table A8).

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Sample #10: KSU bulk stoker ash nitric acid leachate	0.607	3.26	5.24	7.34	1.16	4.75	0.828	0.110	1.66	0.110	0.607	<0.055	0.442	<0.055	0.386	0.166	26.7
Sample #11: KSU bulk stoker ash nitric acid leachate, duplicate	0.650	3.39	5.52	8.08	1.39	5.29	0.789	0.093	1.67	0.186	0.650	<0.046	0.464	<0.046	0.418	0.186	28.8
Sample #12: KSU -200 non-magnetic fraction nitric acid leachate	1.16	7.61	11.2	16.6	1.93	11.3	1.83	0.193	2.12	0.289	1.54	<0.096	1.06	<0.096	0.867	0.193	57.8
Sample #13: KSU carbon fraction nitric acid leachate	0.618	3.35	5.47	9.27	0.529	5.91	0.882	0.088	1.24	<0.088	0.706	<0.088	0.441	<0.088	0.353	0.088	28.9
Sample #14: KSU +200 non-magnetic fraction nitric acid leachate	0.373	1.68	3.83	3.83	<0.093	2.89	0.560	<0.093	0.467	<0.093	0.280	<0.093	0.373	<0.093	0.187	<0.093	14.5
Sample #15: KSU magnetic fraction nitric acid leachate	0.649	3.46	4.47	6.27	0.577	4.47	0.793	0.144	1.44	0.144	0.721	<0.072	0.505	<0.072	0.432	0.144	24.2

Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Maximum value ($\mu\text{g/g}$)	1.16	7.61	11.2	16.6	1.93	11.3	1.83	0.193	2.12	0.289	1.54	---	1.06	---	0.867	0.193	57.8
Minimum value ($\mu\text{g/g}$)	0.373	1.68	3.83	3.83	---	2.89	0.560	---	0.467	---	0.280	---	0.373	---	0.187	---	14.5
% Difference bulk duplicates	6.8	4.0	5.2	9.5	18.2	10.8	4.8	17.3	0.9	50.8	6.8	---	5.0	---	7.8	11.4	7.6
% Change non-magnetic fine vs coarse	210	353	192	333	---	290	227	---	354	---	450	---	184	---	364	---	300
% Change fine vs magnetic	78.2	120	150	164	234	152	131	33.7	47.1	101	114	---	110	---	101	33.7	139

Table A20. Micrograms of REYSc extracted or leached per gram of the plant W samples ($\mu\text{g/g}$) based on the mg/L concentrations (Table A16) and the liquid-to-solid ratios of the nitric acid leachates/extractions (Table A8). The shaded gray sample is an extraction result obtained from a modification of the ASTM D6357-04 procedure (ASTM, 2010).

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Sample #16: Plant W bulk fly ash nitric acid leachate	7.14	19.1	25.0	33.6	6.37	29.0	4.37	1.12	5.60	1.12	4.13	0.177	2.77	<0.059	2.24	0.177	142
Sample #17 Plant W +200 non-magnetic fraction nitric acid leachate	2.32	7.84	14.0	13.0	1.36	12.0	1.74	0.484	2.61	0.290	1.74	<0.097	1.06	<0.097	0.774	0.194	59.4
Sample #18: Plant W +200 non-magnetic fraction nitric acid leachate, duplicate	2.26	7.83	13.9	13.7	1.91	12.4	2.17	0.435	2.70	0.261	1.83	<0.087	1.04	<0.087	0.783	0.174	61.4
Sample #3: Plant W +200 non-magnetic fraction heated nitric acid extraction	2.33	7.81	12.1	14.6	2.98	11.8	2.08	0.490	2.74	0.490	1.80	<0.041	1.06	<0.041	0.817	0.245	61.3
Sample #19: Plant W -200 non-magnetic fraction nitric acid leachate	7.86	20.6	30.6	36.2	6.67	31.2	4.36	1.18	5.92	1.18	4.61	0.249	3.06	0.125	2.43	0.499	157
Sample #20: Plant W carbon fraction nitric acid leachate	10.3	26.6	33.9	52.1	3.74	41.6	6.57	1.59	7.47	1.31	5.95	0.277	3.81	0.138	3.25	0.553	199
Sample #21: Plant W magnetic fraction nitric acid leachate	3.72	12.8	18.2	20.5	3.94	18.5	2.92	0.657	4.02	0.584	2.92	0.073	1.97	<0.073	1.61	0.292	92.7

Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Maximum value ($\mu\text{g/g}$)	10.3	26.6	33.9	52.1	6.67	41.6	6.57	1.59	7.47	1.31	5.95	0.277	3.81	0.138	3.25	0.553	199
Minimum value ($\mu\text{g/g}$)	2.26	7.81	12.1	13.0	1.36	11.8	1.74	0.435	2.61	0.261	1.74	---	1.04	---	0.774	0.174	59.4
% Difference coarse (+200 mesh) ambient duplicates	2.7	0.2	0.9	5.1	34.2	3.6	22.1	10.7	3.1	10.7	4.7	---	2.0	---	1.1	10.7	3.3
% Change hot vs ambient average coarse	1.6	-0.3	13.1	9.3	82.6	-3.7	6.4	6.8	3.2	77.9	0.8	---	0.8	---	5.0	33.5	1.5
% Change non-magnetic fine vs average ambient coarse	243	163	119	172	308	155	123	158	123	330	159	---	190	---	212	171	159
% Change fine vs magnetic	111	61	68	76	69	69	49	80	47	103	58	242	55	---	51	71	69

Table A21. Percentages of REYSc elements leached with nitric acid from the plant D samples. Duplicate results from a second laboratory are listed below the first. As indicated by dashes, some elements were not measured or were below their detection limits in the solid ashes. Maximum and minimum values do not include results involving non-detects in the solid samples or leachates.

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	% Measured REYSc Leached
Sample A: Plant D Composite Nitric Acid	17.5	23.3	25.8	17.7; 22.9	16.6	13.2; 11.1	23.7	27.5	21.3	15.3	28.4	---	19.1	82.6	---	---	19.3; 19.6
Sample B: Plant D Composite Nitric Acid Duplicate	16.8	19.4	24.2	14.9; 20.1	15.9	12.3; 9.9	20.4	25.5	20.1	17.2	27.2	---	18.3	57.3	---	---	17.4; 17.7
Sample E: Plant D Unit 1 row 1 ESP ash acid leachate	17.6	17.3	20.2	17.4	18.9	11.6	23.2	19.3	22.1	15.5	27.3	---	18.0	---	22.2	9.7	16.9
Sample F: Plant D Unit 1 row 1 ESP ash acid leachate, duplicate	17.2	17.9	18.9	17.3	17.3	11.7	26.1	18.6	22.0	15.7	26.9	---	18.6	---	22.2	14.3	16.8
Sample G: Plant D Unit 3 mechanical 3-5 acid leachate	10.8	10.1	13.4	10.7	10.4	7.2	15.6	11.1	14.7	11.8	17.9	---	10.8	---	13.8	7.4	10.6
Sample H: Plant D Unit 3 mechanical 3-7 acid leachate	11.3	10.5	14.0	10.5	12.3	7.1	16.5	10.6	14.5	10.6	18.7	---	11.9	---	13.5	7.6	10.8
Sample I: Plant D Unit 4 mechanical 4-5 acid leachate	12.0	11.6	13.7	10.9	13.2	7.7	16.9	11.3	15.7	14.1	18.7	---	12.7	---	14.1	7.1	11.3
Sample J: Plant D ESP Unit 2 row 1 acid leachate	13.5	11.6	14.1	11.3	13.6	7.8	16.4	12.5	18.3	12.5	20.1	---	13.4	---	15.9	8.9	12.3
Sample L: Plant D carbon fraction nitric acid leachate	13.0	26.7	21.3	17.4	17.2	12.9	20.2	25.9	17.9	9.2	20.5	3.6	16.2	---	19.2	12.3	17.5
Sample M: Plant D magnetic fraction nitric acid leachate	12.4	32.3	25.1	19.1	7.1	15.4	18.2	36.8	7.54	15.8	25.2	3.5	17.1	---	15.2	5.3	17.6
Sample N: Plant D -200 non-magnetic fraction nitric acid leachate	14.5	62.7	27.6	20.7	19.7	13.9	25.8	36.2	26.4	11.5	30.9	4.7	20.9	---	29.0	33.1	22.4
Sample O: Plant D +200 non-magnetic fraction nitric acid leachate, duplicate	7.2	20.2	16.5	9.2	8.2	7.2	11.4	16.5	11.9	4.7	13.1	<1.2	8.8	---	12.2	9.4	10.6
Sample P: Plant D +200 non-magnetic fraction nitric acid leachate	7.1	20.7	17.2	9.1	9.5	7.0	10.7	5.8	13.0	<1.2	11.6	<1.2	8.0	---	12.8	11.6	10.7

Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Maximum value (%)	17.6	62.7	27.6	22.9	19.7	15.4	26.1	36.8	26.4	17.2	30.9	---	20.9	---	29.0	33.1	22.4
Minimum value (%)	7.1	10.1	13.4	9.1	7.1	7.0	10.7	5.8	7.5	<1.2	11.6	---	8.0	---	12.2	5.3	10.6

Table A22. Percentages of REYSc elements extracted or leached with nitric acid from the plant I samples. The shaded gray sample is an extraction result obtained from a modification of the ASTM D6357-04 procedure (ASTM, 2010). Light shaded and italicized values indicate unrealistic recoveries greater than 100%. Maximum and minimum values do not include results involving non-detects in the leachates.

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	% Total REYSc
Sample #4: Plant I bulk fly ash nitric acid leachate	12.3	16.8	14.5	11.8	11.9	17.6	14.4	16.3	18.6	18.6	19.2	4.7	15.4	1.6	17.6	21.4	15.1
Sample #5: Plant I -200 non-magnetic fraction nitric acid leachate	10.4	18.4	14.6	11.3	12.4	15.8	14.4	16.8	17.4	23.5	18.2	3.8	12.5	<2.5	16.2	62.1	13.9
Sample #6: Plant I +200 non-magnetic fraction nitric acid leachate	6.7	11.9	9.9	6.9	2.5	9.9	8.7	12.3	11.2	6.7	10.3	<2.6	8.0	<5.6	11.2	625	8.5
Sample #1: Plant I +200 non-magnetic fraction heated nitric acid extraction	10.8	15.7	14.1	11.1	13.1	14.4	11.6	12.8	17.0	20.9	14.5	1.6	9.4	3.5	13.9	1166	12.9
Sample #7: Plant I carbon fraction acid nitric leachate	20.1	26.5	28.0	24.4	23.2	31.4	24.4	28.5	28.5	31.7	28.3	46.7	22.7	5.0	26.9	30.3	26.4
Sample #8: Plant I magnetic fraction acid nitric leachate	9.0	15.2	14.2	11.2	3.6	17.1	7.3	16.3	17.9	11.3	12.0	<3.5	14.4	<3.1	12.9	5.5	11.8
Sample #9: Plant I magnetic fraction acid nitric leachate, duplicate	8.7	15.0	14.1	10.8	4.0	17.6	6.9	15.3	16.8	9.1	12.0	6.6	14.9	<2.9	12.9	5.2	11.7

Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Maximum value (%)	20.1	26.5	28.0	24.4	23.2	31.4	24.4	28.5	28.5	31.7	28.3	46.7	22.7	---	26.9	1166	26.4
Minimum value (%)	6.7	11.9	9.9	6.9	2.5	9.9	6.9	12.3	11.2	6.7	10.3	---	8.0	---	11.2	5.1	8.5

Table A23. Percentages of REYSc elements leached with nitric acid from the KSU samples. Maximum and minimum values do not include results involving non-detects in the leachates.

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	% Total REYSc
Sample #10: KSU bulk stoker ash nitric acid leachate	1.3	1.5	3.0	1.8	2.7	2.8	2.3	2.4	4.1	1.9	1.8	<0.8	2.0	<1.8	2.1	5.7	2.2
Sample #11: KSU bulk stoker ash nitric acid leachate, duplicate	1.4	1.6	3.2	2.0	3.2	3.1	2.2	2.1	4.1	3.2	1.9	<0.6	2.2	<1.5	2.2	6.4	2.4
Sample #12: KSU -200 non-magnetic fraction nitric acid leachate	2.6	5.0	6.0	4.4	4.2	5.2	4.6	4.1	6.0	7.8	5.6	<1.0	5.0	<2.1	5.3	10.1	4.9
Sample #13: KSU carbon fraction nitric acid leachate	1.2	1.9	2.5	2.2	1.0	2.5	1.9	1.6	3.1	<2.1	2.2	<0.9	1.8	<1.7	1.9	3.2	2.1
Sample #14: KSU +200 non-magnetic fraction nitric acid leachate	0.7	1.1	2.5	1.1	<0.2	1.3	1.5	<2.0	1.4	<2.1	1.0	<1.0	1.7	<1.7	1.0	<4.3	1.3
Sample #15: KSU magnetic fraction nitric acid leachate	1.1	1.7	2.1	1.6	0.8	1.9	1.6	2.4	3.4	2.5	1.9	<0.7	2.0	<1.3	2.0	3.2	1.7

Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Maximum value (%)	2.6	5.0	6.0	4.4	4.2	5.2	4.6	4.1	6.0	7.8	5.6	---	5.0	---	5.3	10.1	4.9
Minimum value (%)	0.7	1.1	2.1	1.1	<0.2	1.3	1.5	---	1.4	---	1.0	---	1.7	---	1.0	---	1.3

Table A24. Percentages of REYSc elements extracted or leached with nitric acid from the plant W samples. The shaded gray sample is an extraction result obtained from a modification of the ASTM D6357-04 procedure (ASTM, 2010). Light shaded gray and italicized values indicate unrealistic recoveries greater than 100%. Maximum and minimum values do not include results involving non-detects in the leachates.

Sample	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	% Total REYSc
Sample #16: Plant W bulk fly ash nitric acid leachate	16.8	17.8	23.1	15.8	26.9	32.9	23.4	28.9	29.8	37.9	23.6	5.0	28.1	<4.2!	25.4	13.5	21.2
Sample #17: Plant W +200 non-magnetic fraction nitric acid leachate	10.4	26.3	31.6	12.8	7.3	22.6	17.4	23.6	25.4	21.9	22.8	<3.3	14.3	<7.1	19.7	<i>342</i>	18.8
Sample #18: Plant W +200 non-magnetic fraction nitric acid leachate, duplicate	10.2	26.3	31.3	13.5	10.3	23.4	21.7	21.2	26.2	19.6	23.9	<3.0	14.0	<6.4	19.9	<i>308</i>	19.4
Sample #3: Plant W +200 non-magnetic fraction heated nitric acid extraction	10.5	26.2	27.3	14.4	16.0	22.1	20.8	23.9	26.7	36.9	23.5	<1.4	14.3	<3.0	20.8	<i>434</i>	19.4
Sample #19: Plant W -200 non-magnetic fraction nitric acid leachate	21.4	32.1	38.1	22.5	22.5	38.6	27.6	34.7	34.4	59.2	34.8	5.2	25.8	5.0	34.5	<i>120</i>	29.5
Sample #20: Plant W carbon fraction nitric acid leachate	18.6	22.9	27.1	22.8	7.9	36.4	26.4	27.2	27.0	32.3	26.1	4.1	21.7	3.8	27.5	36.0	24.5
Sample #21: Plant W magnetic fraction nitric acid leachate	11.9	19.8	25.4	15.9	5.0	29.7	10.8	20.1	23.6	13.5	16.5	4.6	21.8	<3.8	18.5	5.7	17.4

Parameter	Sc	Y	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Total REYSc
Maximum value (%)	21.4	32.1	38.1	22.8	26.9	38.6	27.6	34.7	34.4	59.2	34.8	5.2	28.1	---	34.5	434	29.5
Minimum value (%)	10.2	17.8	23.1	12.8	5.0	22.1	10.8	20.1	23.6	13.5	16.5	---	14.0	---	18.5	5.7	17.4

Table A25. REYSc minerals and other materials with possible REYSc associations that have been found in coal or associated rocks. Illite, as a silicate clay, should be insoluble in nitric acid. Other information on the solubility of minerals in nitric acid was taken from the following websites (these solubility data could not always be confirmed with the peer-reviewed literature):

<http://www.mindat.org/article.php/553/Solubility+Data+on+646+Common+and+Not+So+Common+Minerals>

<http://marulla.com/mineral-solubility/>

Mineral/Phase	Formula	Mineral Group	Coal Reference	Solubility in Nitric Acid
Allanite	Ce,Ca,Y,La) ₂ (Al,Fe ⁺³)(SiO ₄) ₃ (OH)	Silicate	Jeong (2006)	Insoluble
Apatite	Ca ₅ (PO ₄) ₃ (OH,Cl,F)	Phosphate	Birk and White (1991); Jeong (2006); Dai et al. (2016)	Moderate
Biotite	K(Mg,Fe) ₃ (AlSi ₃ O ₁₀)(F,OH) ₂	Silicate	Franus et al. (2015)	Insoluble
Brannerite	U _{0.5} Ca _{0.3} Ce _{0.2} Ti _{1.5} Fe ²⁺ _{0.5} O ₆	Oxide	Dai et al. (2015); Liu et al. (2015)	Soluble
Crandallite	CaAl ₃ (PO ₄)(PO ₃ OH)(OH) ₆	Phosphate	Hower et al. (1999)	?
Florencite	(La,Ce,Nd)Al ₃ (PO ₄) ₂ (OH) ₆	Phosphate	Birk and White (1991); Zhang et al. (2004); Jiang et al. (2015)	?
Glasses	Variable, usually silicate-rich	Non-mineral	Hulett et al. (1980)	Insoluble
Goyazite	SrAl ₃ (PO ₄) ₂ (OH) ₅ •(H ₂ O)	Phosphate	Zou et al. (2014); Jiang et al. (2015)	?
Illite	K(Al,Mg,Fe) ₂ (Si,Al) ₄ O ₁₀ [(OH) ₂ •(H ₂ O)]	Silicate	Birk and White (1991)	Insoluble
Kaolinite	Al ₂ Si ₂ O ₅ (OH) ₄	Silicate	Wang (2009); Franus et al. (2015)	Insoluble
Monazite	(Nd,Ce,La,Th,Sm)PO ₄	Phosphate	Wang (2009)	Slight
Organic Associations	Unknown or varies	Non-mineral	Vassilev et al. (1995)	Varies
Polycrase	Y _{0.5} Ca _{0.1} Ce _{0.1} U _{0.1} Th _{0.1} Ti _{1.2} Nb _{0.6} Ta _{0.3} O ₆	Oxide	Jeong (2006)	?
Rhabdophane	(Ce,La,Nd)PO ₄ •H ₂ O	Phosphate	Zou et al. (2014)	Soluble
Xenotime	(Y,Yb)PO ₄	Phosphate	Birk and White (1991); Jeong (2006)	Insoluble
Zircon	Zr _{0.9} Hf _{0.05} (La,Ce,Y,Pr,Nd,Sm) _{0.05} SiO ₄	Silicate	Birk and White (1991); Jeong (2006); Vassilev and Vassileva (2005)	Insoluble