Appendix A:

Summary of Raw Data

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A.1 Introduction

This evaluation reviewed studies pertaining to either beneficial use products or their raw materials to determine whether the data were appropriate for use in the current evaluation of fly ash concrete and flue gas desulfurization (FGD) gypsum wallboard. This appendix provides an overview of the data sources found to be of sufficient quality, as well as an unaltered reproduction of the raw data contained in each. This evaluation reviewed each source according to the recommendations of *Summary of General Assessment Factors for Evaluating the Quality of Scientific and Technical Information* (US EPA, 2003). Studies included in the evaluation and presented in this Appendix sufficiently describe the analytical methods and assumptions, do not introduce an unacceptable level of uncertainty into the current evaluation, and have an appropriate level of independent review. In most cases, these literature sources were drawn from peer reviewed journals. Some data were submitted directly to the United States Environmental Protection Agency ("EPA" or "the Agency") by generators, regulatory entities, and other interested parties, and have been made available for comment to both the public and a panel of independent peer reviews through a previous EPA risk assessment, *Human and Ecological Risk Assessment of Coal Combustion Wastes* (U.S EPA, 2010). Therefore, the quality of these data is considered sufficient to rely upon in the current beneficial use evaluation.

A.2 Raw Data

This subsection discusses the methodology and provides raw data from each source determined to be of sufficient quality. In order to improve readability, this document may present these data in a format that differs from the one used in the original source. When a given source contained data beyond those listed in this appendix, a rationale for the exclusion of these data is provided in the discussion of that data source.

A.2.1 Coal Combustion Residual (CCR) Constituent Database

The CCR constituent database contains all of the data that EPA has collected over time on the constituents of potential concern (COPCs) concentrations in fly ash. While this database also contains data on COPC concentrations in leachate from raw fly ash, these data are not considered directly applicable to the current evaluation because the leaching rates from raw fly ash cannot be used to predict the exact leaching rates from fly ash concrete. Therefore, these data are not discussed here. The most recent iteration of the database was made available in the 2010 *Risk Assessment* (US EPA, 2010). Since then, the following additional data sources have been made available to the Agency and added to the database:

- *Characterization and Modes of Occurrence of Elements in Feed Coal and Fly Ash - An Integrated Approach* (USGS, 2002) contained data on two fly ashes. Concentrations of the following COPCs were reported for these samples: arsenic, barium, cadmium, chromium, cobalt, lead, mercury, nickel, and uranium. All constituents were analyzed by radiographic techniques.
- *Surface Runoff from Full-Scale Coal Combustion Product Pavements During Accelerated Loading* (Cheng et al., 2008) contained data on COPC concentrations in one fly ash. Concentrations of the

following COPCs were reported for this sample: arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, selenium, silver, strontium, and zinc. COPCs were analyzed by inductively coupled plasma (ICP) atomic emission spectroscopy.

- The Alaska Department of Environmental Conservation provided data for two fly ashes as part of a public comment (ADEC, 2010) on the June 2010 Hazardous and Solid Waste Management System; Identification and Listing of Special Wastes; Disposal of Coal Combustion Residuals from Electric Utilities Proposed Rule (75 FR 35127) ("the 2010 Proposed CCR Disposal Rule"). Concentrations of the following COPCs were reported for these samples: antimony, arsenic, barium, boron, cadmium, chromium, cobalt, lead, mercury, molybdenum, selenium, thallium, uranium, and vanadium. No information was provided on the methods of analysis.
- The University of North Dakota Energy and Environmental Research Center (EERC) provided data for one fly ash sample as part of one public comment on the 2010 Proposed CCR Disposal Rule on behalf of the Coal Ash Resources Research Consortium (EERC, 1991). Concentrations of the following COPCs were reported for these samples: arsenic, chromium, lead, manganese, molybdenum, nickel, strontium, vanadium, and zinc. COPCs were analyzed by flame atomic adsorption or heated graphite furnace atomic adsorption.
- The University of North Dakota EERC provided an additional four fly ash samples in another public comment on the 2010 Proposed CCR Disposal Rule on behalf of the Coal Ash Resources Research Consortium (EERC, 2004). Concentrations of the following COPCs were reported for these samples: antimony, arsenic, beryllium, boron, cadmium, chromium, copper, lead, mercury, nickel, selenium silver, thallium, and zinc. All constituents were analyzed according to American Society for Testing and Materials (ASTM) Method D 4326.
- The University of North Dakota EERC provided an additional 39 fly ash samples from the United States from a study titled *Mercury and Air Toxic Element Impacts of Coal Combustion By-Product Disposal and Utilization*, submitted as a public comment on the 2010 Proposed CCR Disposal Rule (EERC, 2007). Concentrations of one or more of the following COPCs were reported for these samples: arsenic, cadmium, chromium, lead, mercury, nickel, and selenium. Mercury was analyzed according to EPA Method 7471, while all other constituents were analyzed according to EPA Method 6010B or EPA Method 6020.
- The American Coal Ash Association (ACAA) provided data for nine fly ashes from a study titled *Leachability of Trace Metal Elements from Fly Ashes, and from Concrete Incorporating Fly Ash,* which was submitted as a public comment on the 2010 Proposed CCR Disposal Rule (Zhang et al., 2001). Concentrations of the following COPCs were reported for these samples: antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, selenium, silver, uranium, vanadium, and zinc. COPCs were analyzed by atomic adsorption and ICP.
- The ACAA provided data on an additional four fly ashes from the United States from a study titled *Comparative Leaching of Midwestern Fly Ash and Cement*, which was submitted in a public comment on the 2010 Proposed CCR Disposal Rule (Pflughoeft-Hassett et al., 1993). Concentrations of the following COPCs were reported for these samples: arsenic, barium, boron, cadmium,

chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, selenium, silver, vanadium, and zinc. All COPCs were analyzed by inductively coupled plasma - mass spectrometry.

- *Characterization of Coal Combustion Residuals from Electric Utilities – Leaching and Characterization Data* (US EPA, 2009) analyzed 22 fly ash samples for COPC concentrations as part of a data collection effort using the leaching evaluation assessment framework (LEAF) methods. Concentrations of one or more of the following COPCs were reported for these samples: aluminum, antimony, arsenic, barium, cadmium, chromium, cobalt, lead, mercury, molybdenum, selenium, and thallium. Mercury was analyzed according to EPA Method 7470A. All other constituents were analyzed according to EPA Method 6020A.

- *Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States* (USGS, 2011) provided data on 57 samples from four fly ash sources. The fifth sample source was bottom ash, and was not included in the dataset. Concentrations of the following COPCs were reported for these samples: antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, selenium, thallium, uranium, vanadium, and zinc. All constituents were analyzed by radiographic techniques.

- *Effects of Coal Combustion Fly Ash Use in Concrete on Liquid-Solid Partitioning of Constituents of Potential Concern* Kosson et al. (2013) provided data collected on four fly ashes. Concentrations of the following COPCs were reported for these samples: antimony, arsenic, barium, boron, cadmium, chromium, lead, molybdenum, selenium, thallium, and vanadium. Boron, barium, and vanadium were analyzed according to EPA Method 6010C, while all other constituents were analyzed according to EPA Method 6020A. Of the four samples, only three were incorporated into the dataset. The fourth fly ash (Sample ID: FaFA) was previously sampled in US EPA (2009).

Table A-1 provides the raw data on COPC fly ash concentrations available in the CCR Constituent Database. When utilizing these data, the current evaluation averaged muiltiple data points for a single sample source into a single data point to avoid biasing the overall data set towards any single sample source. In addition, the evaluation incorporated non-detect values using half of the reported detection limit based on the recommendations in *Risk Assessment Guidance for Superfund (RAGS) Part A* (US EPA, 1989) and with *EPA Region 3 Guidance on Handling Chemical Concentration Data near the Detection Limit in Risk Assessments* (US EPA, 1991). In several cases, non-detect values were not the lowest values reported for a given data due to the range of detection limits found across the different data sets. In six instances, the evaluation removed individual non-detects from the dataset. Specifically:

- For antimony, the detection limit of 1,370 milligrams per kilogram (mg/kg) in two samples was nearly 10 times higher than the highest detected value.

- For mercury, the detection limit of 7.4 mg/kg in one sample was nearly two times higher than highest detected value.

- For silver, one detection limit of 21 mg/kg and two detection limits of 19.3 mg/kg were nearly two times higher than the highest detected value.

These non-detect data points were removed because they are not representative of actual COPC concentrations and introduce an articially high level of uncertainty into the measured datasets.

Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
ADEC (2010)	AES-102210-01	--	16.0	160	550	--	260	12.0	95.0	31.0	--	--	300	--	4.2	11.0	--	37	--	--	< 10.0	17.0	210	--
ADEC (2010)	UAF-102210-01	--	< 8.0	< 9.0	3,700	--	150	0.55	48.0	20.0	--	--	4.3	--	0.03	1.4	--	< 7.0	--	--	< 14.0	2.5	130	--
Cheng et al. (2008)	Fly Ash	--	--	10.0	1,161	< 4.0	--	< 17.0	155	52.0	0.06	--	36.3	316	< 0.50	< 8.0	104	< 1.0	< 21.0	789	--	--	--	91.0
DPC (1991)	DPC 90771/2	10,400	0.77	104	51.4	--	754	0.84	50.2	--	39.3	10,200	52.8	209	0.25	14.3	32.7	6.7	--	--	--	--	--	102
EERC (1991)	Gibson Fly Ash	--	--	20.6	--	--	--	--	214	--	--	--	162	223	--	63.9	139	--	--	236	--	--	302	563
EERC (2004)	Coyote	--	6.2	82.0	--	2.2	982	1.5	25.3	--	71.8	--	59.6	--	0.32	--	30.3	< 1.3	2.0	--	2.1	--	--	48.9
EERC (2004)	Coal Creek	--	11.5	105	--	6.6	976	4.2	55.0	--	68.0	--	38.1	--	< 0.13	--	40.7	< 2.7	2.2	--	< 2.0	--	--	118
EERC (2004)	Stanton	--	2.7	30.8	--	3.3	771	0.55	32.0	--	37.6	--	25.5	--	< 0.13	--	45.0	< 2.5	3.2	--	< 1.9	--	--	63.5
EERC (2004)	Hoot Lake	--	9.7	50.2	--	2.8	409	12.3	55.5	--	190	--	27.2	--	< 0.13	--	57.9	1.3	6.3	--	< 1.0	--	--	122
EERC (2007)	02-070	--	--	--	--	--	--	--	--	--	--	--	--	--	0.19	--	--	--	--	--	--	--	--	--
EERC (2007)	02-070	--	--	--	--	--	--	--	--	--	--	--	--	--	0.20	--	--	--	--	--	--	--	--	--
EERC (2007)	02-072	--	--	--	--	--	--	--	--	--	--	--	--	--	0.16	--	--	--	--	--	--	--	--	--
EERC (2007)	02-073	--	--	--	--	--	--	--	--	--	--	--	--	--	0.23	--	--	--	--	--	--	--	--	--
EERC (2007)	02-074	--	--	--	--	--	--	--	--	--	--	--	--	--	0.61	--	--	--	--	--	--	--	--	--
EERC (2007)	03-004	--	--	72.2	--	--	--	< 1.0	142	--	--	--	65.4	--	0.10	--	68.3	7.9	--	--	--	--	--	--
EERC (2007)	03-005	--	--	71.4	--	--	--	< 1.0	148	--	--	--	72.6	--	0.08	--	85.7	8.5	--	--	--	--	--	--
EERC (2007)	03-006	--	--	78.0	--	--	--	1.4	135	--	--	--	94.3	--	0.19	--	60.4	13.6	--	--	--	--	--	--
EERC (2007)	03-007	--	--	68.6	--	--	--	1.1	138	--	--	--	89.0	--	0.14	--	55.2	11.4	--	--	--	--	--	--
EERC (2007)	03-007	--	--	72.1	--	--	--	< 1.0	135	--	--	--	72.4	--	--	--	87.2	12.2	--	--	--	--	--	--
EERC (2007)	03-016	--	--	33.7	--	--	--	< 1.0	59.6	--	--	--	25.6	--	0.02	--	59.5	13.0	--	--	--	--	--	--
EERC (2007)	03-061	--	--	37.8	--	--	--	1.8	44.2	--	--	--	58.1	--	0.58	--	79.0	44.3	--	--	--	--	--	--
EERC (2007)	03-061	--	--	49.2	--	--	--	1.5	76.1	--	--	--	62.1	--	--	--	107	44.7	--	--	--	--	--	--
EERC (2007)	03-061	--	--	43.4	--	--	--	1.9	82.4	--	--	--	58.4	--	--	--	95.8	--	--	--	--	--	--	--
EERC (2007)	03-063	--	--	45.5	--	--	--	< 1.0	128	--	--	--	37.1	--	< 0.10	--	23.3	4.9	--	--	--	--	--	--

COPC = constituent of potential concern
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit

Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
EERC (2007)	03-078	--	--	--	--	--	--	--	--	--	--	--	--	--	0.66	--	--	--	--	--	--	--	--	--
EERC (2007)	03-079	--	--	351	--	--	--	2.1	83.2	--	--	--	68.3	--	0.79	--	40.9	14.7	--	--	--	--	--	--
EERC (2007)	03-080	--	--	157	--	--	--	1.1	66.1	--	--	--	39.9	--	0.44	--	63.5	11.9	--	--	--	--	--	--
EERC (2007)	03-081	--	--	492	--	--	--	3.6	85.2	--	--	--	124	--	0.46	--	68.4	18.1	--	--	--	--	--	--
EERC (2007)	03-083	--	--	163	--	--	--	3.5	134	--	--	--	258	--	0.02	--	252	4.8	--	--	--	--	--	--
EERC (2007)	03-083	--	--	169	--	--	--	3.7	139	--	--	--	272	--	--	--	266	4.0	--	--	--	--	--	--
EERC (2007)	03-085	--	--	145	--	--	--	2.6	124	--	--	--	247	--	0.03	--	277	4.0	--	--	--	--	--	--
EERC (2007)	03-088	--	--	44.0	--	--	--	8.6	160	--	--	--	249	--	0.01	--	74.5	7.4	--	--	--	--	--	--
EERC (2007)	04-003	--	--	49.8	--	--	--	*< 1.0*	138	--	--	--	60.4	--	0.69	--	77.2	19.3	--	--	--	--	--	--
EERC (2007)	04-003	--	--	42.2	--	--	--	*< 1.0*	132	--	--	--	60.5	--	--	--	75.9	19.1	--	--	--	--	--	--
EERC (2007)	04-004	--	--	31.5	--	--	--	*< 1.0*	144	--	--	--	55.7	--	0.04	--	81.6	5.8	--	--	--	--	--	--
EERC (2007)	04-006	--	--	5.9	--	--	--	*< 1.0*	43.8	--	--	--	38.8	--	0.14	--	26.1	10.2	--	--	--	--	--	--
EERC (2007)	04-007	--	--	7.1	--	--	--	*< 1.0*	64.9	--	--	--	29.1	--	0.52	--	22.0	13.5	--	--	--	--	--	--
EERC (2007)	04-029	--	--	31.1	--	--	--	1.1	63.7	--	--	--	38.6	--	0.26	--	39.9	15.7	--	--	--	--	--	--
EERC (2007)	04-035	--	--	36.0	--	--	--	*< 1.0*	55.4	--	--	--	21.9	--	0.16	--	17.2	9.8	--	--	--	--	--	--
EERC (2007)	04-042	--	--	--	--	--	--	--	--	--	--	--	--	--	0.37	--	--	--	--	--	--	--	--	--
EERC (2007)	04-043	--	--	--	--	--	--	--	--	--	--	--	--	--	0.69	--	--	--	--	--	--	--	--	--
EERC (2007)	04-044	--	--	--	--	--	--	--	--	--	--	--	--	--	0.88	--	--	--	--	--	--	--	--	--
EERC (2007)	04-045	--	--	--	--	--	--	--	--	--	--	--	--	--	0.85	--	--	--	--	--	--	--	--	--
EERC (2007)	05-001	--	--	24.4	--	--	--	*< 1.0*	45.1	--	--	--	17.4	--	*< 0.01*	--	30.3	8.8	--	--	--	--	--	--
EERC (2007)	05-005	--	--	--	--	--	--	--	--	--	--	--	--	--	0.43	--	--	--	--	--	--	--	--	--
EERC (2007)	05-010	--	--	--	--	--	--	--	--	--	--	--	--	--	0.08	--	--	--	--	--	--	--	--	--
EERC (2007)	05-018	--	--	--	--	--	--	--	--	--	--	--	--	--	0.12	--	--	--	--	--	--	--	--	--
EERC (2007)	05-038	--	--	43.4	--	--	--	*< 1.0*	43.4	--	--	--	90.1	--	0.10	--	21.1	23.4	--	--	--	--	--	--

COPC = constituent of potential concern
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit

Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
EPRI (1983)	SW 013080 D111F	138,000	--	23.2	3,160	--	--	*< 0.10*	36.7	--	--	24,000	74.0	197	0.13	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 013080 D112F	132,000	--	28.2	3,050	--	--	*< 0.10*	35.9	--	--	24,000	71.0	199	*< 0.005*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 013080 D121F	145,000	--	31.1	3,250	--	--	*< 0.10*	27.7	--	--	25,300	70.0	209	0.14	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 013080 D211F	129,000	--	20.7	3,170	--	--	*< 0.10*	28.0	--	--	24,400	66.0	201	0.17	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 013080 S111F	143,000	--	29.7	3,180	--	--	*< 0.10*	28.0	--	--	24,900	68.0	204	0.11	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 013180 D111F	145,000	--	41.4	3,120	--	--	*< 0.10*	27.9	--	--	24,400	74.0	195	0.12	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 013180 D112F	139,000	--	29.8	3,040	--	--	*< 0.10*	40.4	--	--	24,400	69.0	195	0.14	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 013180 D121F	109,000	--	17.9	3,140	--	--	*< 0.10*	27.8	--	--	23,600	73.0	183	0.18	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 013180 D211F	142,000	--	25.6	3,180	--	--	*< 0.10*	27.9	--	--	24,800	71.0	202	0.11	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 013180 S111F	135,000	--	32.2	3,070	--	--	*< 0.10*	23.7	--	--	23,600	73.0	186	0.09	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020280 D111F	149,000	--	33.3	2,430	--	--	2.0	32.4	--	--	23,000	54.0	175	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020280 D112F	143,000	--	27.6	2,650	--	--	*< 0.10*	32.6	--	--	22,900	67.0	177	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020280 D121F	147,000	--	35.3	3,010	--	--	3.4	29.6	--	--	22,800	50.0	175	0.06	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020280 D211F	147,000	--	31.1	2,860	--	--	2.3	31.4	--	--	22,200	35.0	167	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020280 S111F	145,000	--	41.8	3,170	--	--	3.1	26.6	--	--	24,200	41.0	191	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020380 D111F	146,000	--	34.7	3,200	--	--	3.8	29.7	--	--	24,600	44.0	194	0.05	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020380 D112F	141,000	--	26.8	3,140	--	--	*< 0.10*	36.0	--	--	24,500	64.0	196	0.05	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020380 D121F	146,000	--	37.6	3,090	--	--	3.6	29.9	--	--	24,500	51.0	193	0.05	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020380 D211F	144,000	--	33.4	3,120	--	--	3.8	27.3	--	--	24,200	40.0	191	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020380 S111F	148,000	--	43.8	3,010	--	--	3.4	29.9	--	--	23,100	47.0	177	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--

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Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
EPRI (1983)	SW 020580 D111F	138,000	--	30.8	3,200	--	--	3.4	36.8	--	--	24,900	40.0	198	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020580 D112F	133,000	--	25.1	3,150	--	--	*< 0.10*	37.3	--	--	24,800	69.0	201	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020580 D121F	145,000	--	38.6	3,230	--	--	2.9	33.0	--	--	25,200	43.0	195	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020580 D211F	144,000	--	42.3	3,150	--	--	3.3	28.4	--	--	24,800	49.0	196	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020580 S111F	144,000	--	41.5	3,080	--	--	3.2	34.3	--	--	24,500	48.0	189	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020680 D111F	146,000	--	39.1	2,840	--	--	5.6	34.1	--	--	25,000	56.0	184	0.05	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020680 D112F	146,000	--	29.6	2,860	--	--	*< 0.10*	37.4	--	--	25,600	70.0	193	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020680 D121F	146,000	--	42.5	2,860	--	--	2.7	31.3	--	--	24,900	55.0	184	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020680 D211F	142,000	--	44.0	3,220	--	--	3.3	34.2	--	--	25,800	49.0	199	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020680 S111F	144,000	--	41.0	2,170	--	--	3.8	25.5	--	--	25,600	49.0	200	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020880 D111F	146,000	--	40.4	3,100	--	--	2.9	28.3	--	--	24,900	51.0	189	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020880 D112F	142,000	--	30.3	3,070	--	--	*< 0.10*	37.2	--	--	24,600	62.0	192	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020880 D121F	142,000	--	39.1	3,180	--	--	2.5	27.9	--	--	25,000	49.0	189	0.05	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020880 D211F	108,000	--	25.8	3,130	--	--	2.0	25.5	--	--	24,900	47.0	183	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020880 S111F	144,000	--	29.3	3,040	--	--	1.9	32.6	--	--	24,900	48.0	181	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020980 D111F	145,000	--	38.9	3,050	--	--	2.8	34	--	--	24,700	53.0	173	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020980 D112F	142,000	--	28.9	3,120	--	--	*< 0.10*	35.7	--	--	24,500	70.0	178	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020980 D121F	131,000	--	29.6	3,180	--	--	3.1	35.5	--	--	25,400	36.0	175	0.06	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020980 D211F	127,000	--	28.4	3,080	--	--	2.9	29.7	--	--	24,800	41.0	170	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 020980 S111F	146,000	--	39.5	3,120	--	--	2.6	31.1	--	--	24,700	53.0	167	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--

COPC = constituent of potential concern
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit

Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
EPRI (1983)	SW 021180 D111F	95,400	--	23.6	2,840	--	--	2.5	28.3	--	--	24,000	50.0	166	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 021180 D112F	92,100	--	18.7	2,860	--	--	*< 0.10*	34.3	--	--	23,600	70.0	170	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 021180 D121F	145,000	--	37.1	2,850	--	--	3.3	28.0	--	--	24,800	46.0	175	0.04	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 021180 D211F	149,000	--	36.0	2,970	--	--	2.4	25.2	--	--	25,200	48.0	179	*< 0.025*	--	--	*< 0.6*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 021180 S111F	148,000	--	46.0	3,010	--	--	3.1	31.2	--	--	25,100	52.0	175	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 021280 D111F	147,000	--	37.9	3,190	--	--	2.7	29.5	--	--	26,300	49.0	173	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 021280 D112F	141,000	--	25.7	3,220	--	--	*< 0.10*	44.6	--	--	25,200	70.0	173	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 021280 D121F	105,000	--	25.2	3,160	--	--	3.0	30.7	--	--	25,400	34.0	160	0.04	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 021280 D211F	148,000	--	41.2	3,260	--	--	3.4	30.9	--	--	26,000	47.0	172	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 021280 S111F	148,000	--	41.7	3,090	--	--	3.2	32.5	--	--	25,600	55.0	178	*< 0.025*	--	--	*< 0.60*	*< 0.25*	--	--	--	--	--
EPRI (1983)	SW 042480 D111F	119,000	--	39.7	3,160	--	--	*< 1.1*	11.4	--	--	25,100	58.1	187	0.10	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042480 G111F	121,000	--	35.0	2,370	--	--	*< 1.1*	8.4	--	--	24,900	61.3	234	0.07	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042480 G112F	128,000	--	50.0	2,410	--	--	*< 1.1*	--	--	--	24,000	71.1	231	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042480 S111F	121,000	--	37.4	2,810	--	--	*< 1.1*	10.9	--	--	24,700	68.9	170	0.08	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042480 S112F	126,000	--	50.7	2,920	--	--	*< 1.1*	16.3	--	--	23,900	78.7	167	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042580 D111F	119,000	--	32.7	2,420	--	--	*< 1.1*	10.2	--	--	25,000	54.6	236	0.07	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042580 D112F	126,000	--	46.9	2,470	--	--	*< 1.1*	17.7	--	--	23,800	69.4	230	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042580 S111F	119,000	--	32.1	2,650	--	--	*< 1.1*	9.8	--	--	26,500	61.8	195	0.06	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042580 S112F	122,000	--	44.5	2,660	--	--	*< 1.1*	18.9	--	--	24,800	69.2	185	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042780 D111F	115,000	--	32.7	2,490	--	--	*< 1.1*	10.5	--	--	24,100	70.8	159	--	--	--	--	--	--	--	--	--	--

COPC = constituent of potential concern
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit

Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
EPRI (1983)	SW 042780 D112F	124,000	--	48.6	2,600	--	--	< 1.1	18.8	--	--	23,700	70.8	158	0.07	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042780 G111F	118,000	--	41.6	2,400	--	--	< 1.1	11.2	--	--	24,100	78.7	165	0.04	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042780 G112F	124,000	--	44.5	2,480	--	--	< 1.1	19.4	--	--	22,900	88.6	158	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042780 S111F	118,000	--	44.3	2,440	--	--	< 1.1	9.9	--	--	23,800	71.3	154	0.07	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042780 S112F	124,000	--	49.7	2,500	--	--	< 1.1	19.9	--	--	23,000	78.7	151	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042880 D111F	116,000	--	36.6	2,140	--	--	< 1.1	12.5	--	--	23,800	68.3	166	0.04	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042880 D112F	124,000	--	41.5	2,240	--	--	< 1.1	19.4	--	--	23,100	75.6	163	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042880 S111F	114,000	--	41.3	2,490	--	--	< 1.1	11.0	--	--	23,400	76.3	149	0.03	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 042880 S112F	122,000	--	44.5	2,640	--	--	< 1.1	14.9	--	--	22,800	83.6	147	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 043080 D111F	117,000	--	28.5	2,170	--	--	< 1.1	6.6	--	--	25,100	51.7	178	0.06	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 043080 D112F	124,000	--	40.1	2,300	--	--	< 1.1	17.3	--	--	24,500	54.1	176	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 043080 G111F	116,000	--	35.6	2,570	--	--	< 1.1	8.0	--	--	24,800	64.2	183	0.07	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 043080 G112F	123,000	--	43.2	2,650	--	--	< 1.1	15.3	--	--	24,000	42.0	178	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 043080 S111F	117,000	--	25.0	2,570	--	--	< 1.1	8.6	--	--	25,400	66.2	181	0.09	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 043080 S112F	124,000	--	36.5	2,620	--	--	< 1.1	16.6	--	--	24,600	41.7	177	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050180 D111F	114,000	--	38.5	2,290	--	--	< 1.1	7.8	--	--	24,900	59.3	175	0.13	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050180 D112F	126,000	--	37.1	2,480	--	--	< 1.1	15.1	--	--	25,400	46.9	180	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050180 S111F	113,000	--	30.4	2,200	--	--	< 1.1	8.0	--	--	24,600	59.3	174	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050180 S112F	122,000	--	38.8	2,330	--	--	< 1.1	13.7	--	--	24,600	39.5	175	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050680 D111F	112,000	--	18.5	2,500	--	--	< 1.1	19	--	--	24,600	49.4	188	< 0.01	--	--	--	--	--	--	--	--	--

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Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
EPRI (1983)	SW 050680 D112F	122,000	--	30.1	2,680	--	--	< 1.1	14.9	--	--	24,900	32.1	190	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050680 G111F	114,000	--	24.7	2,460	--	--	< 1.1	18.8	--	--	23,500	61.8	178	0.08	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050680 G112F	124,000	--	36.8	2,590	--	--	< 1.1	16.1	--	--	23,800	44.5	180	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050680 S111F	114,000	--	16.9	2,460	--	--	< 1.1	19.5	--	--	22,700	62.3	172	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050680 S112F	125,000	--	37.8	2,630	--	--	< 1.1	16.1	--	--	23,000	44.8	175	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050780 D111F	113,000	--	23.3	2,470	--	--	< 1.1	19.8	--	--	23,100	70.5	178	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050780 D112F	123,000	--	29.2	2,610	--	--	< 1.1	15.3	--	--	23,100	43.7	179	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050780 S111F	115,000	--	24.1	2,290	--	--	< 1.1	15.7	--	--	23,500	64.0	185	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050780 S112F	123,000	--	31.7	2,420	--	--	< 1.1	16.0	--	--	23,100	44.3	183	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050980 D111F	114,000	--	24.7	2,240	--	--	< 1.1	16.1	--	--	23,100	61.3	184	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050980 D112F	124,000	--	23.0	2,380	--	--	< 1.1	16.8	--	--	25,300	44.1	185	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050980 G111F	112,000	--	22.0	2,530	--	--	< 1.1	15.7	--	--	22,800	44.5	167	0.03	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050980 G112F	--	--	25.7	--	--	--	< 1.1	15.1	--	--	--	44.5	--	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050980 S111F	112,000	--	28.8	2,500	--	--	< 1.1	13.0	--	--	20,900	68.3	129	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 050980 S112F	121,000	--	29.6	2,690	--	--	< 1.1	12.7	--	--	22,900	46.9	169	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051080 D111F	114,000	--	30.3	2,690	--	--	< 1.1	13.0	--	--	21,400	47.1	135	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051080 D112F	124000	--	39.2	2840	--	--	< 1.1	13.3	--	--	21,600	47.1	136	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051080 S111F	115,000	--	24.1	2,750	--	--	< 1.1	16.0	--	--	21,700	44.6	143	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051080 S112F	122,000	--	25.5	2,800	--	--	< 1.1	15.8	--	--	21,100	34.7	139	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051280 D111F	110,000	--	25.3	2,370	--	--	< 1.1	12.0	--	--	27,800	36.9	193	< 0.01	--	--	--	--	--	--	--	--	--

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Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
EPRI (1983)	SW 051280 D112F	117,000	--	25.8	2,450	--	--	< 1.1	12.2	--	--	27,500	34.4	191	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051280 G111F	113,000	--	31.6	2,180	--	--	< 1.1	14.4	--	--	23,300	51.9	146	< 0.04	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051280 G112F	120,000	--	40.0	2,230	--	--	< 1.1	17.4	--	--	22,700	42	142	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051280 S111F	107,000	--	23.0	2,250	--	--	< 1.1	16.1	--	--	28,400	29.6	204	< 0.04	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051280 S112F	113,000	--	25.7	2,330	--	--	< 1.1	15.4	--	--	28,100	29.6	202	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051380 D111F	112,000	--	24.3	1,920	--	--	< 1.1	17.6	--	--	23,600	44.6	175	< 0.04	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051380 D112F	117,000	--	25.0	1,950	--	--	< 1.1	16.1	--	--	22,600	34.7	168	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051380 S111F	110,000	--	25.9	2,060	--	--	< 1.1	16.5	--	--	23,700	51.2	177	< 0.04	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051380 S112F	112,000	--	27.8	2,040	--	--	< 1.1	17.0	--	--	22,100	41.5	165	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051480 D111F	112,000	--	24.6	1,600	--	--	< 1.1	19.5	--	--	25,400	51.7	153	< 0.04	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051480 D112F	141,000	--	32.2	1,950	--	--	< 1.1	16.6	--	--	27,600	49.2	150	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051480 S111F	131,000	--	23.1	1,660	--	--	< 1.1	17.8	--	--	27,100	56.6	142	< 0.04	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051480 S112F	140,000	--	31.0	1,730	--	--	< 1.1	17.2	--	--	27,200	54.1	134	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051580 D111F	126,000	--	25.1	1,760	--	--	< 1.1	17.9	--	--	25,400	57.3	136	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051580 D112F	135,000	--	33.4	1,870	--	--	< 1.1	17.8	--	--	25,600	54.8	129	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051580 G111F	121,000	--	29.5	1,870	--	--	< 1.1	15	--	--	24,800	54.1	137	0.06	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051580 G112F	129,000	--	33.5	1,970	--	--	< 1.1	14.8	--	--	25,200	51.7	130	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051580 S111F	109,000	--	25.9	2,000	--	--	< 1.1	18.1	--	--	23,400	57.3	125	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051580 S112F	121,000	--	33.9	2,090	--	--	< 1.1	15.2	--	--	23,600	57.3	118	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051680 D111F	122,000	--	30.1	2,240	--	--	< 1.1	14.7	--	--	23,900	46.9	156	0.03	--	--	--	--	--	--	--	--	--

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Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
EPRI (1983)	SW 051680 D112F	131,000	--	35.3	2,330	--	--	< 1.1	15.3	--	--	24,200	51.9	148	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051680 S111F	119,000	--	24.7	2,240	--	--	< 1.1	14.3	--	--	21,500	49.4	158	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051680 S112F	125,000	--	28.2	2,300	--	--	< 1.1	14.3	--	--	21,700	49.4	148	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051780 D111F	118,000	--	29.4	2,310	--	--	< 1.1	15.5	--	--	21,800	52.3	175	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051780 D112F	124,000	--	31.9	2,350	--	--	< 1.1	16.2	--	--	21,900	52.3	164	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051780 S111F	118,000	--	25.6	2,440	--	--	< 1.1	15.5	--	--	22,700	49.8	182	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051780 S112F	125,000	--	29.9	2,480	--	--	< 1.1	18.4	--	--	23,100	49.8	172	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051880 D111F	117,000	--	36.9	2,130	--	--	< 1.1	16.1	--	--	21,400	49.2	161	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051880 D112F	126,000	--	34.4	2,230	--	--	< 1.1	17.8	--	--	22,100	54.1	155	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051880 S111F	116,000	--	26.1	2,210	--	--	< 1.1	16.2	--	--	22,000	49.2	168	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051880 S112F	124,000	--	33.7	2,300	--	--	< 1.1	17.6	--	--	22,600	51.7	161	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051980 D111F	115,000	--	26.8	1,710	--	--	< 1.1	21.2	--	--	23,600	52.1	168	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051980 D112F	123,000	--	28.8	1,800	--	--	< 1.1	22.7	--	--	24,000	49.6	159	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051980 S111F	120,000	--	24.6	1,430	--	--	< 1.1	23.8	--	--	24,000	54.6	159	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 051980 S112F	126,000	--	31.7	1,510	--	--	< 1.1	24.8	--	--	24,000	54.6	148	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 052180 D111F	113,000	--	24.4	1,740	--	--	< 1.1	22.7	--	--	23,300	52.3	164	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 052180 D112F	124,000	--	27.4	1,900	--	--	< 1.1	22.3	--	--	24,800	57.3	161	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 052180 G111F	110,000	--	24.5	1,660	--	--	< 1.1	22.9	--	--	22,400	51.9	153	< 0.01	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 052180 G112F	120,000	--	32.1	1,800	--	--	< 1.1	23.4	--	--	23,600	54.3	149	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 052180 S111F	112,000	--	31.1	1,540	--	--	< 1.1	21.3	--	--	21,800	64.7	143	< 0.01	--	--	--	--	--	--	--	--	--

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Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
EPRI (1983)	SW 052180 S112F	125,000	--	38.8	1,710	--	--	*< 1.1*	21.9	--	--	23,400	62.3	143	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 052280 D111F	126,000	--	31.4	2,130	--	--	*< 1.1*	18.7	--	--	26,000	51.9	177	*< 0.01*	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 052280 D112F	118,000	--	33.6	1,890	--	--	*< 1.1*	18.6	--	--	23,400	54.3	154	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 052280 S111F	122,000	--	26.9	2,180	--	--	*< 1.1*	17.3	--	--	23,900	57.3	157	*< 0.01*	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 052280 S112F	123,000	--	29.9	2,090	--	--	*< 1.1*	18.2	--	--	23,300	62.3	146	--	--	--	--	--	--	--	--	--	--
EPRI (1983)	SW 053590 D112F	128,000	--	44.8	3,260	--	--	*< 1.1*	20.1	--	--	24,600	70.2	188	--	--	--	--	--	--	--	--	--	--
EPRI (1996)	Cleveland 1996 2-2	26,000	--	47.0	--	--	186	*< 0.17*	--	--	--	69,400	13.0	98.0	--	--	49.0	10.0	--	--	--	--	--	34.0
EPRI (1998)	SFA	--	--	180	1,370	--	--	--	--	--	890	--	80.0	--	--	--	130	--	--	810	--	--	300	210
EPRI (1998)	STK-1	--	--	130	1,160	--	--	--	--	--	*< 25.0*	--	140	--	--	--	*< 10*	--	--	920	--	--	320	330
EPRI (1998)	STK-2	--	--	110	1,010	--	--	--	--	--	*< 25.0*	--	140	--	--	--	*< 10.0*	--	--	780	--	--	340	290
EPRI (1999)	Baldwin IP B	--	--	50.0	416	15.8	--	11.3	449	59.2	226	--	133	414	--	--	275	--	--	--	--	--	517	1433
EPRI (1999)	Bowden GP B	--	--	68.0	974	22.1	--	0.70	168	79.9	221	--	63.9	187	--	--	130	--	--	--	--	--	307	141
EPRI (1999)	Cardinal AEP C1	--	--	85.0	375	10.1	--	1.0	162	46.1	64.2	--	43.5	366	--	--	144	--	--	--	--	--	267	160
EPRI (1999)	Cardinal AEP C2	--	--	178	--	--	--	1.3	179	--	93.9	--	54.0	241	--	--	137	--	--	--	--	--	304	209
EPRI (1999)	Lone Mtn SRTC LM	--	--	76.0	1,483	24.0	--	11.9	149	87.3	221	--	69.8	228	--	--	196	--	--	--	--	--	562	169
EPRI (1999)	Miller AP M	--	--	18.0	7,140	2.2	--	1.6	59.6	42.3	349	--	38.0	534	--	--	130	--	--	--	--	--	309	90.5
EPRI (1999)	Paradise TVA P	--	--	75.0	--	10.0	--	5.2	149	--	289	--	76.0	367	--	--	162	--	--	--	--	--	471	583
EPRI (1999)	Pleasant Prairie WE PP	--	--	38.0	6,220	3.2	--	1.8	114	54.1	331	--	43.5	313	--	--	93.8	--	--	--	--	--	331	159
EPRI (1999)	Sioux A S1	--	--	95.0	420	9.1	--	4.2	163	135	417	--	253	208	--	--	169	--	--	--	--	--	310	5337
EPRI (1999)	Sioux A S1	--	--	74.0	--	8.6	--	2.4	107	--	347	--	159	171	--	--	207	--	--	--	--	--	379	2662

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Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
EPRI (1999)	Stanton OU S	--	--	63.0	1,370	28.5	--	0.90	170	86.1	230	--	65.2	285	--	--	70.2	--	--	--	--	--	316	153
EPRI (1999)	Yates GP Y	--	--	106	--	16.6	--	0.90	181	--	230	--	46.0	339	--	--	147	--	--	--	--	--	351	154
EPRI (2001)	Xcel/MSI MN1	--	2.4	11.9	4,747	1.5	596	1.2	37.0	13.0	--	30,989	50.0	153	0.6	7.6	16.0	15.1	1.9	--	0.40	--	196	54.0
EPRI (2001)	Xcel/MSI MN10	--	2.3	19.0	6,606	5.3	550	2.0	75.0	27.7	--	36,018	50.0	138	0.24	8.9	66.0	20.8	1.7	--	0.48	--	160	175
EPRI (2001)	Xcel/MSI MN11	--	2.6	17.4	6,870	5.2	569	1.7	74.0	29.9	--	37,403	51.6	129	0.16	10.2	68.0	25.2	1.9	--	0.68	--	165	157
EPRI (2001)	Xcel/MSI MN12a	--	6.6	26.3	432	3.6	2005	1.9	78.0	32.4	--	43,885	68.8	321	0.81	105	979	29.4	1.9	--	0.41	--	1537	160
EPRI (2001)	Xcel/MSI MN2	--	2.7	15.4	5,973	3.8	1,084	1.2	89.0	24.6	--	41,183	50.6	133	0.25	8.6	41.0	20.2	1.4	--	0.50	--	181	72.0
EPRI (2001)	Xcel/MSI MN3	--	2.5	15.4	4,241	3.6	669	1.2	81.0	26.2	--	41,319	46.7	136	0.48	8.7	46.0	20.8	1.5	--	0.45	--	190	89.0
EPRI (2001)	Xcel/MSI MN4	--	3.7	14.7	134	2.4	1,392	0.78	47.0	16.9	--	28,290	23.3	487	0.19	25.0	165	17.7	1.3	--	0.38	--	312	59.0
EPRI (2001)	Xcel/MSI MN5	--	3.8	13.9	139	2.2	1,329	0.55	35.0	13.4	--	24,825	21.1	558	0.02	13.2	27.0	18.2	1.2	--	0.47	--	56.0	50.0
EPRI (2001)	Xcel/MSI MN6	--	3.7	14.6	246	2.7	1,296	0.78	58	18.3	--	30,073	27.7	412	0.20	10.0	33.0	21.0	1.4	--	0.37	--	109	61.0
EPRI (2001)	Xcel/MSI MN7	--	2.6	15.5	5,395	3.9	806	1.2	95	26.1	--	44,666	46.1	162	0.30	8.8	52.0	21.3	1.5	--	0.51	--	202	103
EPRI (2001)	Xcel/MSI MN8	--	2.4	17.0	6,589	4.7	602	1.7	72	28.2	--	36,885	49.1	139	0.27	9.6	66.0	21.5	1.7	--	0.49	--	167	173
EPRI (2001)	Xcel/MSI MN9	--	2.5	15.6	6,719	4.6	480	1.8	91	26.2	--	37,132	54.5	135	0.29	8.2	98.0	23.9	1.8	--	0.51	--	182	160
Finkelman et al. (1998)	Unit 1 (High Sulfur)	--	15.0	90.0	--	18.0	--	7.8	161	53.1	--	--	200	300	--	--	300	6.8	--	--	--	14.1	--	--
Finkelman et al. (1998)	Unit 3 (Low Sulfur)	--	7.9	35.0	--	19.0	--	*< 0.80*	169	79.2	--	--	100	180	--	--	152	14.1	--	--	--	11.4	--	--
Hower et al. (1993)	CAER 91965	--	--	133	393	--	--	--	179	72.0	21.0	--	123	75.0	--	91.0	156	--	--	481	--	--	429	570
Hower et al. (1993)	CAER 91966	--	--	75.5	426	--	--	--	182	78.0	14.0	--	76.5	242	--	97.0	127	--	--	437	--	--	530	495
Hower et al. (1993)	CAER 91967	--	--	112	392	--	--	--	203	76.0	42.0	--	109	242	--	92.0	195	--	--	540	--	--	367	570
Hower et al. (1993)	CAER 91988	--	--	189	640	--	--	--	136	71.0	45.0	--	75.2	224	--	38.0	151	--	--	1,290	--	--	241	179

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Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
Hower et al. (1993)	CAER 91990	--	--	70.1	1,020	--	--	--	106	34.0	91.0	--	88.7	54.0	--	15.0	96.0	--	--	2,950	--	--	218	134
Hower et al. (2001)	Kentucky 92607	--	--	468	--	--	--	--	283	--	298	--	--	179	--	--	397	--	--	275	--	--	702	2,420
Hower et al. (2001)	Kentucky 92611	--	--	627	--	--	--	--	156	--	166	--	--	99.0	--	--	244	--	--	183	--	--	233	1,840
Hower et al. (2001)	Kentucky 92614	--	--	302	--	--	--	--	212	--	230	--	327	135	--	--	233	--	--	238	--	--	410	5,750
Hower et al. (2001)	Kentucky 92632	--	--	773	--	--	--	--	220	--	252	--	342	166	--	--	810	--	--	152	--	--	1,400	6,220
IDNR (1999)	Deer Ridge Mine 030796	2,297	--	31.5	42.7	--	1,216	0.80	11.5	--	74.3	6,982	55.6	16.8	0.26	1.4	139	15.6	< 0.001	--	--	--	22.8	365
IDNR (1999)	Deer Ridge Mine 030797	120,000	--	6.8	630	--	34.0	< 1.0	170	--	200	45,000	14.0	130	< 0.01	2.6	490	1.4	< 1.0	--	--	--	260	430
IDNR (1999)	Deer Ridge Mine 060195-1	2,260	--	0.03	34.0	--	126	0.50	10.7	--	89.9	5,547	80.4	17.9	0.11	4.1	177	18.6	3.5	--	--	--	< 0.05	22.7
IDNR (1999)	Deer Ridge Mine 061196	1,589	--	22.6	25.6	--	< 0.04	0.08	13.4	--	96.3	4,495	92.1	10.2	0.02	2.2	90.4	18.7	0.08	--	--	--	30.8	188
IDNR (1999)	Deer Ridge Mine 061397-1	140,000	--	23.0	740	--	40.0	< 1.0	180	--	260	69,000	19.0	180	0.04	19.0	570	4.6	< 1.0	--	--	--	320	470
IDNR (1999)	Deer Ridge Mine 091296	25,000	--	0.27	0.71	--	< 2.5	0.01	0.19	--	0.64	130	0.71	0.24	< 0.01	0.03	1.4	0.17	< 0.05	--	--	--	0.25	8.1
IDNR (1999)	Deer Ridge Mine 092695	1,891	--	27.7	648	--	145	< 0.003	0.06	--	66.3	5,096	126	24.0	0.37	3.7	121	14.0	0.10	--	--	--	17.0	282
IDNR (1999)	Deer Ridge Mine 092797	97,000	--	59.0	360	--	65.0	4.7	47.0	--	140	52,000	73.0	110	0.03	29	470	34.0	10.0	--	--	--	170	370
IDNR (1999)	Deer Ridge Mine 111797	1,753	--	25.0	48.0	--	124	1.3	8.1	--	72.0	4,429	81.0	17.0	0.14	2.5	226	12.0	< 0.35	--	--	--	22.0	517
IDNR (1999)	Deer Ridge Mine 121996	280,000	--	17.0	56.0	--	41.0	< 0.05	10.0	--	51.0	35,000	43.0	9.4	0.17	1.7	57.0	12.0	0.05	--	--	--	22.0	210
IDNR (1999)	Little Sandy#10 Mine 120792-1	--	--	220	150	--	530	2.2	63.0	--	110	40,000	240	86	0.04	15	270	41.0	< 1.3	--	--	--	--	600
IDNR (1999)	Miller Creek 012198-2	10,000	--	267	97.0	--	388	1.5	28.0	--	75.0	29,370	580	52.0	< 0.04	14	178	3.6	4.3	--	--	--	75.0	599
IDNR (1999)	Miller Creek 031998	8,580	--	71.0	150	--	161	< 0.10	21.0	--	39.0	11,730	35.0	115	< 0.13	4.7	36.0	3.0	5.2	--	--	--	45.0	241
IDNR (1999)	Miller Creek 040597	7,930	--	186	61.0	--	233	21.0	31.0	--	35.0	51,200	126	53.0	0.25	18	120	9.0	< 0.06	--	--	--	73.0	317
IDNR (1999)	Miller Creek 040896-2	19,379	--	122	120	--	1.4	2.8	39.0	--	71.5	55,739	89.5	102	0.26	13.1	139	9.7	7.8	--	--	--	67.0	170

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IDNR (1999)	Miller Creek 100997	10,590	--	163	112	--	447	12.0	35.0	--	56.0	33,150	95.0	116	0.08	20.0	135	22.0	3.2	--	--	--	--	153
IDNR (1999)	Miller Creek 122292-1	--	--	35.0	37.0	--	150	*< 0.65*	16.0	--	15.0	15,000	30.0	51.0	*< 0.013*	2.7	18.0	*< 12.5*	*< 1.3*	--	--	--	--	40.0
IDNR (1999)	Miller Creek 122292-2	--	--	33.0	47.0	--	200	*< 0.65*	24.0	--	17.0	18,000	37.0	74.0	*< 0.013*	3.0	19.0	*< 12.5*	*< 1.3*	--	--	--	--	63.0
IDNR (1999)	Miller Creek 122292-3	--	--	110	40.0	--	200	*< 0.65*	22.0	--	18.0	19,000	43.0	71.0	*< 0.013*	3.0	19.0	*< 12.5*	*< 1.3*	--	--	--	--	60.0
IDNR (1999)	Miller Creek 122292-4	--	--	52.0	67.0	--	310	*< 0.65*	39.0	--	26.0	18,000	53.0	76.0	*< 0.013*	4.4	32.0	*< 12.5*	*< 1.3*	--	--	--	--	110
IDNR (1999)	Miller Creek 122292-5	--	--	25.0	39.0	--	160	*< 0.65*	21.0	--	18.0	19,000	31.0	71.0	*< 0.013*	3.3	21.0	*< 12.5*	*< 1.3*	--	--	--	--	63.0
Kim & Kazonich (2001)	NETL 10	--	--	*< 100*	3,310	*< 5.0*	--	*< 5.0*	*< 50.0*	*< 50.0*	50.0	--	*< 50.0*	--	--	--	*<50.0*	7.3	--	--	--	--	--	65.0
Kim & Kazonich (2001)	NETL 11	--	--	*< 100*	859	*< 5.0*	--	10.0	173	*< 50.0*	115	--	113	--	--	--	*<50.0*	11.0	--	--	--	--	--	202
Kim & Kazonich (2001)	NETL 12	--	--	*< 100*	893	*< 5.0*	--	*< 5.0*	165	*< 50.0*	119	--	112	--	--	--	*<50.0*	9.6	--	--	--	--	--	207
Kim & Kazonich (2001)	NETL 13	--	--	*< 100*	866	*< 5.0*	--	*< 50*	164	*< 50.0*	112	--	109	--	--	--	*< 50.0*	11.6	--	--	--	--	--	188
Kim & Kazonich (2001)	NETL 14	--	--	*< 50.0*	456	12.0	--	15.0	184	40.0	93.0	--	71.0	--	--	--	124	7.6	--	--	--	--	--	175
Kim & Kazonich (2001)	NETL 15	--	--	229	844	14.0	--	15.0	185	42.0	158	--	124	--	--	--	106	8.5	--	--	--	--	--	235
Kim & Kazonich (2001)	NETL 16	--	--	301	1,160	13.0	--	15.0	170	42.0	139	--	121	--	--	--	109	7.8	--	--	--	--	--	204
Kim & Kazonich (2001)	NETL 17	--	--	*< 50.0*	471	*< 2.5*	--	*< 7.5*	132	*< 12.5*	72.0	--	81.0	--	--	--	71.0	17.7	--	--	--	--	--	204
Kim & Kazonich (2001)	NETL 18	--	--	77.0	529	2.0	--	*< 0.50*	97.0	11.0	76.0	--	*< 0.50*	--	--	--	85.0	1.4	--	--	--	--	--	124
Kim & Kazonich (2001)	NETL 19	--	--	125	511	6.0	--	*< 0.50*	111	16.0	76.0	--	0.50	--	--	--	92.0	1.8	--	--	--	--	--	155
Kim & Kazonich (2001)	NETL 2	--	--	*< 50.0*	95	*< 2.5*	--	*< 12.5*	*< 25*	*< 25*	*< 12.5*	--	*< 25*	--	--	--	*< 25.0*	2.3	--	--	--	--	--	11.0
Kim & Kazonich (2001)	NETL 20	--	--	277	1,380	10.0	--	*< 0.50*	110	44.0	155	--	*< 0.50*	--	--	--	135	1.6	--	--	--	--	--	197
Kim & Kazonich (2001)	NETL 21	--	--	148	849	12.0	--	*< 0.50*	92.0	31.0	122	--	*< 0.50*	--	--	--	125	1.9	--	--	--	--	--	128
Kim & Kazonich (2001)	NETL 22	--	--	29.0	1,520	*< 0.025*	--	*< 0.50*	53.0	*< 0.25*	71.0	--	*< 0.50*	--	--	--	37.0	3.7	--	--	--	--	--	46.0
Kim & Kazonich (2001)	NETL 23	--	--	44.0	999	*< 0.025*	--	*< 0.50*	55.0	*< 0.03*	42.0	--	*< 0.50*	--	--	--	35.0	3.2	--	--	--	--	--	33.0
Kim & Kazonich (2001)	NETL 24	--	--	53.0	789	14.0	--	*< 0.50*	176	59.0	152	--	134	--	--	--	120	1.9	--	--	--	--	--	113
Kim & Kazonich (2001)	NETL 25	--	--	143	699	4.0	--	*< 0.50*	136	23.0	74.0	--	116	--	--	--	84.0	3.7	--	--	--	--	--	136

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Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
Kim & Kazonich (2001)	NETL 26	--	--	44.0	469	6.0	--	1.1	114	33.0	53.0	--	12.0	--	--	--	124	1.4	--	--	--	--	--	34.0
Kim & Kazonich (2001)	NETL 27	--	--	28.0	765	18.0	--	*< 2.5*	176	86.0	156	--	65.0	--	--	--	137	8.6	--	--	--	--	--	112
Kim & Kazonich (2001)	NETL 28	--	--	69.0	703	19.0	--	*< 2.5*	211	79.0	176	--	99.0	--	--	--	131	7.8	--	--	--	--	--	121
Kim & Kazonich (2001)	NETL 29	--	--	142	2,010	26.0	--	*< 2.5*	179	76.0	246	--	110	--	--	--	149	17.5	--	--	--	--	--	112
Kim & Kazonich (2001)	NETL 3	--	--	*< 50.0*	76	9.0	--	*< 12.5*	*< 25.0*	*< 25.0*	51.0	--	*< 25.0*	--	--	--	59.0	90.7	--	--	--	--	--	43.0
Kim & Kazonich (2001)	NETL 30	--	--	90.0	781	11.0	--	*< 0.05*	205	50.0	117	--	24.0	--	--	--	119	13.3	--	--	--	--	--	139
Kim & Kazonich (2001)	NETL 31	--	--	175	951	27.0	--	*< 0.05*	193	73.0	255	--	109	--	--	--	171	19.6	--	--	--	--	--	252
Kim & Kazonich (2001)	NETL 32	--	--	104	721	11.0	--	6.4	183	25.0	76.0	--	116	--	--	--	124	16.1	--	--	--	--	--	438
Kim & Kazonich (2001)	NETL 33	--	--	91.0	892	9.0	--	*< 0.05*	181	42.0	79.0	--	77.0	--	--	--	101	8.6	--	--	--	--	--	140
Kim & Kazonich (2001)	NETL 36	--	--	144	1,070	19.0	--	1.8	174	21.0	1610	--	173	--	--	--	482	18.7	--	--	--	--	--	609
Kim & Kazonich (2001)	NETL 4	--	--	*< 50.0*	121	*< 2.5*	--	*< 12.5*	*< 25.0*	*< 25.0*	*< 12.5*	--	*< 25*	--	--	--	*< 25.0*	5.0	--	--	--	--	--	16.0
Kim & Kazonich (2001)	NETL 5	--	--	*< 50.0*	155	*< 2.5*	--	*< 12.5*	*< 25.0*	*< 25.0*	*< 12.5*	--	*< 25*	--	--	--	*< 25.0*	4.4	--	--	--	--	--	23.0
Kim & Kazonich (2001)	NETL 6	--	--	171	1,140	11.0	--	*< 5.0*	175	41.0	114	--	90.0	--	--	--	107	4.8	--	--	--	--	--	201
Kim & Kazonich (2001)	NETL 7	--	--	166	1,090	10.0	--	*< 5.0*	170	39.0	105	--	64.0	--	--	--	107	4.8	--	--	--	--	--	191
Kim & Kazonich (2001)	NETL 8	--	--	67.0	855	8.0	--	*< 5.0*	171	31.0	74.0	--	59.0	--	--	--	1,040	2.8	--	--	--	--	--	135
Kosson et al. (2013)	FA02	--	*< 3.0*	47.0	730	--	350	24.0	160	--	--	--	*< 2.6*	--	--	6.7	--	*< 5.8*	--	--	*< 1.8*	--	260	--
Kosson et al. (2013)	FA18	--	*< 3.0*	13	6,800	--	440	11.0	69.0	--	--	--	4.4	--	--	6.0	--	*< 5.8*	--	--	*< 1.8*	--	170	--
Kosson et al. (2013)	FA39	--	*< 3.0*	*< 4.2*	8,100	--	630	12.0	59.0	--	--	--	4.3	--	--	6.7	--	*< 5.8*	--	--	*< 1.8*	--	210	--
PADEP (2001)	B-D Mining Co. 092988-2	48,065	39.0	1.8	294	--	50.0	2.0	59.0	--	53.0	26,670	40.0	86.0	0.25	3.5	25.0	0.50	2.0	--	--	--	--	28.0
PADEP (2001)	B-D Mining Co. 092988-3	32,216	37.0	1.9	194	--	25.0	2.4	48.0	--	30.0	19,941	28.0	63.0	0.17	--	18.0	0.44	1.0	--	--	--	--	21
PADEP (2001)	B-D Mining Co. 093090-1	32,560	42.0	25.7	267	--	18.0	1.3	70.4	--	30.8	24,810	43.2	81.7	0.33	--	22.4	--	--	--	--	--	--	19.9
PADEP (2001)	B-D Mining Co. 100189-1	56,900	51.0	6.9	692	--	50.0	1.5	104	--	65.8	32,980	71.0	120	0.37	--	56.7	--	--	--	--	--	--	39.3
PADEP (2001)	B-D Mining Co. 100189-2	62,500	36.0	5.6	670	--	53.0	--	90.3	--	65.7	32,260	68.0	92.6	0.35	--	51.5	--	--	--	--	--	--	35.0

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Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
PADEP (2001)	B-D Mining Co. 101190-1	33,340	55.0	37.8	273	--	23.0	1.3	76	--	38.6	31,390	45.5	91.4	0.48	--	26.6	--	--	--	--	--	--	19.8
PADEP (2001)	Harrim 3019 AES 10061998	41,000	--	12.0	223	--	125	--	63.0	38.0	49.0	16,000	20.0	84.0	0.20	17.0	56.0	--	2.0	--	--	--	--	43.5
PADEP (2001)	Harrim 3019 AES 11081995	50,000	--	59.1	323	--	82.0	--	66.4	29.7	49.6	26,500	44.2	68.9	0.19	15.8	55.5	1.8	2.3	--	--	--	--	89.7
PADEP (2001)	Harrim 3019 AES 11281997	37,100	--	37.0	365	--	85.3	--	66.0	35.0	49.0	21,300	21.0	76.0	--	16.0	57.0	1.1	--	--	--	--	--	49.6
PADEP (2001)	Harrim 3019 AES 4281994	105,920	*< 1,370*	38.7	*< 319*	--	135	--	142	179	91.4	36,300	46.6	85.6	--	--	104	--	*< 19.3*	--	--	--	--	70.1
PADEP (2001)	Harrim 3019 AES 5241999	31,400	20.0	4.3	298	--	94.9	--	534	--	53.0	16,500	10.0	82.0	0.54	--	352	--	--	--	--	--	--	37.2
PADEP (2001)	Harrim 3019 AES 5281998	20,600	20.0	12.1	280	--	170	0.50	61.0	14.0	18.0	30,300	10.0	57.0	0.44	22.0	41.0	0.50	1.0	--	--	--	--	40.0
PADEP (2001)	Harrim 3019 AES 6111997	93,000	--	63.0	--	--	21.5	--	9.0	29.0	14.0	26,000	--	38.0	--	--	47.0	1.0	--	--	--	--	--	47.1
PADEP (2001)	Harrim 3019 AES 9101996	17,800	47.0	13.0	210	--	--	--	26.0	20.0	49.0	11,800	--	7.0	0.10	19.0	34.0	0.90	2.0	--	--	--	--	31.0
PADEP (2001)	Harrim 3004 042894-1	105,920	*< 1,370*	38.7	*< 319*	--	135	*< 2.5*	142	179	91.4	36,300	46.6	85.6	*< 7.4*	*< 8.9*	104	*< 3.9*	*< 19.3*	--	--	--	--	70.1
PADEP (2001)	Harrim 3004 110895-1	50,000	--	59.1	323	--	82.0	--	66.4	29.7	49.6	26,500	44.2	68.9	0.19	15.8	55.5	1.8	2.3	--	--	--	--	89.7
PADEP (2001)	Harriman 052400-2	29,200	20.0	23.3	530	--	148	4.0	40.0	--	55.0	13,600	26.0	109	0.29	14.0	43.0	19.1	--	--	--	--	--	39.0
PADEP (2001)	Harriman 110200-1	77,200	*< 10.0*	17.5	376	--	158	0.50	71.0	--	75.0	20,000	36.0	65	*< 0.01*	14.0	59.0	33.0	--	--	--	--	--	33.4
PADEP (2001)	Northeastern Energy Company TSEC-1	8,800	*< 0.40*	12	160	--	130	*< 0.40*	26.0	--	55.0	10,000	19.0	120	0.13	1.2	31.0	21.0	--	--	--	--	--	54.0
PADEP (2001)	Northeastern Power Company 041900-1	26,100	0.85	22.5	239	--	13.3	0.63	27.0	--	27.3	8,210	31.6	186	0.97	3.2	10.9	11.4	--	--	--	--	--	25.4
PADEP (2001)	Northeastern Power Company 042099-3	28,200	--	18.3	243	--	7.1	--	28.2	--	32.8	12,700	26.6	52.5	1.0	3.1	11.9	13.4	--	--	--	--	--	17.3
PADEP (2001)	Northeastern Power Company 042590-1	33,500	--	8.4	271	--	--	--	31.8	--	--	7,910	16.1	50.0	1.8	--	--	13.9	--	--	--	--	--	

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Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
PADEP (2001)	Northeastern Power Company 042590-2	26,860	--	8.7	254	--	--	--	28.9	--	--	5,890	6.9	48.0	1.6	--	--	12.9	--	--	--	--	--	
PADEP (2001)	Northeastern Power Company 042590-3	36,400	--	9.4	281	--	--	--	39.3	--	--	9,120	23.9	54.8	1.0	--	--	14.1	--	--	--	--	--	
PADEP (2001)	Northeastern Power Company 050890-1	6,500	--	--	5.0	--	28.5	1.0	14.0	--	10.5	500	15.0	20.0	--	--	--	--	0.50	--	--	--	--	10.5
PADEP (2001)	Northeastern Power Company 052294-1	21,900	--	13.7	195	--	0.71	1.9	28.0	--	26.5	5,240	40.6	51.5	0.40	64.4	9.7	51.0	4.2	--	--	--	--	11.1
PADEP (2001)	Northeastern Power Company 052391-1	4,660	--	--	35	--	34	--	--	--	8.5	958	50.0	18.0	--	20.0	--	--	--	--	--	--	--	13.0
PADEP (2001)	Northeastern Power Company 060193-1	1,400	--	9.6	130	--	392	--	15.5	--	14.5	2,160	17.5	27.5	0.59	--	8.0	1.8	0.50	--	--	--	--	10.0
PADEP (2001)	Northeastern Power Company 060695-3	29,750	--	10.9	151	--	19.7	0.67	16.9	3.1	20.7	5,960	37.9	47.4	0.285	0.31	8.4	--	2.3	--	--	--	--	15.6
PADEP (2001)	Northeastern Power Company 110199-3	12,200	--	11.1	122	--	3.4	--	10.7	--	17.7	3,860	14.4	2030	--	1.5	6.1	3.8	--	--	--	--	--	10.8
PADEP (2001)	Northeastern Power Company 110600-2	21,300	*< 0.37*	18.2	199	--	2.9	*< 0.37*	18.7	--	26.4	11500	25.2	64.3	0.83	3.2	10.4	8.5	--	--	--	--	--	17.5
PADEP (2001)	Northeastern Power Company 111593-1	19,330	0.01	2.5	160	--	--	1.5	22.7	--	19.1	5,165	36.0	38.6	0.55	44.6	7.8	46.5	--	--	--	--	--	9.8
PADEP (2001)	Northeastern Power Company 111892-1	20,000	3.5	1.0	150	--	136	1.0	23.5	--	18.5	2,550	25.0	51.0	0.51	16.7	13	1.2	0.50	--	--	--	--	16.5
PADEP (2001)	Northeastern Power Company 111896-3	28,700	5.6	1.7	213	--	--	0.33	34.7	3.2	20.0	11,700	17.8	28.9	--	0.83	10.4	5.3	10.2	--	--	--	--	8.2
PADEP (2001)	Northeastern Power Company 112995-3	43,100	--	10.3	256	--	37.9	1.4	31.2	3.6	24.0	7,580	58.0	38.2	--	0.56	10.7	--	--	--	--	--	--	19.5

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PADEP (2001)	Northeastern Power Company 120194-3	22,400	--	10.0	150	--	25.3	1.8	23.3	--	21.9	4,720	39.2	43.6	0.08	0.28	7.8	--	3.7	--	--	--	--	15.3
PADEP (2001)	Pacton Corp 031990-1	70,200	< 4.0	100	1,010	--	58.0	24.0	150	--	120	45,500	220	460	0.20	10	100	4.0	< 2.5	--	--	--	--	150
PADEP (2001)	Pacton Corp 031990-2	124,300	< 4.0	220	2,760	--	110	30.0	360	--	310	100,700	120	380	--	50.0	200	4.0	< 2.5	--	--	--	--	320
PADEP (2001)	Pacton Corp 080189-1	140,000	80.0	1.9	710	--	27.0	16.0	170	--	210	34,200	83.0	120	0.40	8.0	190	7.4	4.0	--	--	--	--	120
PADEP (2001)	Pacton Corp 111989-1	156,000	20.0	8.4	360	--	428	< 2.5	84.0	--	120	41,700	63.0	200	0.40	5.0	58.0	4.0	< 2.5	--	--	--	--	89.0
PADEP (2001)	Pagnotti Coal Co. 061289-1	40,000	0.21	250	800	--	3.0	0.25	46.0	--	53.5	19,500	72.5	115	0.01	50.0	2.0	0.10	0.50	--	--	--	--	125
PADEP (2001)	Pagnotti Coal Co. 083089-1F	45,000	--	--	--	--	--	--	--	--	--	2,150	--	--	--	--	--	--	--	--	--	--	--	--
Pflughoeft-Hassett et al. (1993)	FA1	--	--	12.0	6,400	--	610	< 1.0	51.0	39.0	175	--	23.0	120	0.23	< 10	31.0	< 0.4	< 0.20	--	-	--	180	43.0
Pflughoeft-Hassett et al. (1993)	FA2	--	--	37.0	5,000	--	1,200	< 1.0	74.0	51.0	280	--	20.0	380	0.61	67.0	960	20.0	< 0.20	--	-	--	1,800	290
Pflughoeft-Hassett et al. (1993)	FA3	--	--	68.0	16,000	--	770	< 1.0	54.0	30.0	210	--	9.8	360	0.32	19.0	28.0	17.0	< 0.20	--	-	--	210	100
Pflughoeft-Hassett et al. (1993)	FA4	--	--	100	6,500	--	1,100	< 1.0	69.0	24.0	65.0	--	19.0	780	0.10	13.0	34.0	9.8	< 0.20	--	-	--	120	75.0
Pflughoeft-Hassett et al. (2000)	Coal Creek CCFA	--	--	0.13	5.2	--	1.3	0.001	0.06	--	--	--	0.03	--	0.0003	--	--	0.01	--	--	--	--	--	--
PPL Generation (2002)	Martins Creek 218771	110,342	< 5.0	145	430	4.0	350	4.0	280	256	52.1	76,429	--	40.9	--	--	121	< 3.8	--	915	--	--	65.3	93.5
PPL Generation (2002)	Martins Creek 234269	125,471	< 5.0	75.7	380	3.0	345	< 1.0	214	< 24.8	52.8	58,013	--	63.2	--	--	77.1	< 2.2	--	674	--	--	226	81.2
PPL Generation (2002)	Martins Creek 253822	115,000	48.0	73.5	638	< 0.5	425	< 1.0	218	< 33	89.5	74,000	--	73.9	--	--	80.3	15.4	--	962	--	--	165	121
PPL Generation (2002)	Martins Creek 260520	140,553	< 5.0	60.4	675	6.0	520	2.0	149	< 35.4	60.9	68,836	--	94.6	--	--	85.4	< 4.0	--	775	--	--	154	91.5
PPL Generation (2002)	Martins Creek FSV-00-00010	118,000	< 2.5	< 5.4	170	2.9	290	< 0.25	165	< 27.4	55.1	71,500	--	81.8	--	--	66.3	< 2.4	--	893	--	--	221	86.0
PPL Generation (2002)	Martins Creek FSV-01-00009	85,300	7.1	218	1,427	12.0	162	0.81	196	< 24.2	126	59,000	--	71.5	--	--	74.5	< 3.1	--	781	--	--	< 25.0	127
PPL Generation (2002)	Martins Creek FSV-96-00329	137,300	< 5.0	96.7	396	--	457	3.0	173	< 26.9	50.8	67,880	--	79.3	--	--	81.0	< 3.0	--	542	--	--	< 24.5	114

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Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
PPL Generation (2002)	Martins Creek FSV-97-00102	123,600	*< 5.0*	33.0	920	4.0	640	*< 1.0*	201	*< 40.6*	66.5	65,220	--	96.1	--	--	40.3	*< 3.9*	--	951	--	--	114	69.9
PPL Generation (2002)	Martins Creek FSV-99-00043	80,500	*< 5.0*	123	550	5.0	559	*< 1.0*	183	*< 13.4*	50.9	34,700	--	47.0	--	--	65.4	*< 2.3*	--	711	--	--	*< 14.7*	113
US EPA (2009)	Brayton Point	--	--	81.0	--	--	--	0.90	--	--	--	32,185	117	--	0.65	--	--	51	--	--	--	--	--	--
US EPA (2009)	Facility Aa Unit 1	85,200	4.1	31.0	935	--	--	0.52	141	53.0	--	--	55.0	--	0.23	13.0	--	17	--	--	2.0	--	--	--
US EPA (2009)	Facility Aa Unit 3	82,000	5.2	36.0	900	--	--	0.68	134	55.0	--	--	60.0	--	0.34	15.0	--	30	--	--	2.2	--	--	--
US EPA (2009)	Facility Aa Unit 4	83,200	11	73.0	1,113	--	--	0.76	136	50.0	--	--	74.0	--	0.01	22.0	--	1.1	--	--	4.4	--	--	--
US EPA (2009)	Facility A	127,100	14	71.0	1,016	--	--	1.3	152	55.0	--	--	81.0	--	0.6	17.0	--	26	--	--	3.8	--	--	--
US EPA (2009)	Facility B	109,400	3.6	82.0	1,461	--	--	0.9	192	24.0	--	--	47.0	--	0.09	11.0	--	2.5	--	--	4.7	--	--	--
US EPA (2009)	Facility Ca	77,200	6.2	22.0	955	--	--	1.7	88	21.0	--	--	56.0	--	0.10	19.0	--	8.6	--	--	1.5	--	--	--
US EPA (2009)	Facility A	138,200	8.2	88.0	1,361	--	--	1.0	151	49.0	--	--	69.0	--	0.38	15.0	--	22	--	--	3.2	--	--	--
US EPA (2009)	Facility Da	103,600	7.0	58.0	1,297	--	--	0.77	170	66.0	--	--	72.0	--	0.19	17.0	--	13	--	--	2.3	--	--	--
US EPA (2009)	Facility B	105,900	2.8	90.0	1,360	--	--	0.70	169	21.0	--	--	36.0	--	0.11	11.0	--	2.9	--	--	4.5	--	--	--
US EPA (2009)	Facility J	--	--	43.0	--	--	--	1.4	--	--	--	--	46.0	--	0.11	--	--	11	--	--	13.0	--	--	--
US EPA (2009)	Facility K	123,200	6.0	85.0	585	--	--	1.0	124	38.0	--	--	93.0	--	0.04	23.0	--	4.8	--	--	6.0	--	--	--
US EPA (2009)	Facility L	--	--	20.0	--	--	--	0.4	--	--	--	--	45.0	--	0.01	--	--	4.0	--	--	--	--	--	--
US EPA (2009)	Pleasant Prairie	--	--	21.0	--	--	--	--	--	--	--	--	42.0	--	0.16	--	--	--	--	--	--	--	--	--
US EPA (2009)	Salem Harbor	--	--	26.0	--	--	--	--	--	--	--	--	25.0	--	0.57	--	--	42.0	--	--	--	--	--	--
US EPA (2009)	Facility T	93,100	5.5	155	839	--	--	0.92	142	27.0	--	--	55.0	--	0.75	19.0	--	9.0	--	--	13.0	--	--	--
US EPA (2009)	Facility U	92,200	6.3	42.0	2,143	--	--	14.0	214	22.0	--	--	55.0	--	0.02	77.0	--	3.8	--	--	2.3	--	--	--
US EPA (2009)	Facility W	130,600	4.2	32.0	1,229	--	--	0.78	122	38.0	--	--	46.0	--	0.16	11.0	--	13.0	--	--	0.99	--	--	--
US EPA (2009)	Facility X	98,900	4.2	36.0	6,306	--	--	1.8	129	29.0	--	--	51.0	--	0.46	22.0	--	15.0	--	--	0.81	--	--	--
US EPA (2009)	Facility Z Unit 7	68,600	2.5	17.0	6,907	--	--	1.5	70.0	34.0	--	--	41.0	--	0.35	8.4	--	11.0	--	--	0.72	--	--	--
US EPA (2009)	Facility Z unit 6	73,800	3.0	22.0	7,034	--	--	1.6	74.0	31.0	--	--	55.0	--	0.63	9.4	--	14.0	--	--	--	--	--	--
US EPA (2009)	Facility C	--	--	94.0	--	--	--	--	--	--	--	--	56.0	--	0.02	--	--	--	--	--	--	--	--	--

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Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
USGS (2002)	Kentucky	--	--	170	600	--	--	5.5	170	59.0	--	--	150	--	0.39	--	220	--	--	--	--	19.0	--	--
USGS (2002)	Indiana	--	--	18.0	7,400	--	--	1.0	95	31.0	--	--	42.0	--	0.01	--	75	--	--	--	--	9.0	--	--
USGS (2011)	Illinois Basin 7019003	--	2.3	23.0	395	2.8	--	0.89	93.2	25.9	170	--	27.0	146	0.03	5.8	69.2	6.5	--	--	0.47	6.1	297	179
USGS (2011)	Illinois Basin 7019004	--	2.5	25.3	367	3.0	--	1.0	104	28.2	209	--	30.9	182	0.03	7.2	75.1	8.1	--	--	0.50	6.8	330	307
USGS (2011)	Illinois Basin 7019005	--	2.4	24.0	355	2.6	--	1.1	102	28.0	202	--	31.2	163	0.03	6.6	67.2	11.4	--	--	0.49	6.9	323	179
USGS (2011)	Illinois Basin 7019006	--	2.4	24.2	360	2.6	--	1.0	96.7	26.7	195	--	31.9	161	0.04	6.4	64.8	8.5	--	--	0.49	6.8	317	191
USGS (2011)	Illinois Basin 7019007	--	2.2	23.0	336	2.6	--	0.85	88.6	26.6	173	--	27.3	141	0.06	6.1	64.3	22.5	--	--	0.46	6.1	295	163
USGS (2011)	Illinois Basin 7019008	--	22.4	25.1	352	32.7	--	3.3	984	264	692	--	293	723	0.06	90.5	572	14.0	--	--	21.0	34.1	1,660	848
USGS (2011)	Illinois Basin 7019009	--	2.5	23.7	410	2.7	--	0.98	99.2	26.6	189	--	30.7	158	0.01	6.5	68.1	5.9	--	--	0.61	6.5	324	183
USGS (2011)	Illinois Basin 7019010	--	2.3	21.9	422	2.6	--	0.89	89.6	24.4	172	--	26.8	137	0.02	6.1	61.5	6.2	--	--	0.48	6.1	296	161
USGS (2011)	Illinois Basin 7019011	--	2.1	20.2	383	2.3	--	0.79	78.2	22.5	156	--	24.6	139	0.02	5.3	58.2	5.8	--	--	0.44	5.3	262	145
USGS (2011)	Illinois Basin 7019012	--	2.2	23.3	352	2.8	--	0.87	87.3	25.1	175	--	26.1	174	0.02	5.9	64.8	5.7	--	--	0.44	6.1	291	187
USGS (2011)	Illinois Basin 7019013	--	4.4	56.3	418	5.5	--	1.1	142	36.2	167	--	36.3	199	0.02	17.8	95	4.1	--	--	1.3	7.2	364	237
USGS (2011)	Illinois Basin 7019014	--	2.0	25.2	375	3.5	--	0.81	89.5	28	171	--	22.1	182	0.03	6.1	75.2	8.7	--	--	0.38	6.2	262	122
USGS (2011)	Illinois Basin 7019015	--	3.9	24.5	408	3.6	--	1.4	144	26.8	239	--	44.0	105	0.10	8.2	67.5	4.8	--	--	0.67	8.5	434	195
USGS (2011)	San Juan Basin E0709002-144	--	3.1	18.4	1,610	5.4	--	0.6	34.2	15.1	67.2	--	66.4	189	0.09	8.8	20.1	6.7	--	--	1.1	12.6	109	75.9
USGS (2011)	San Juan Basin E0709002-145	--	3.0	18.7	1,600	5.1	--	0.58	34.2	15.2	66.7	--	63.6	194	0.07	8.6	18.1	9.8	--	--	1.1	12.2	111	75.2
USGS (2011)	San Juan Basin E0709002-146	--	2.8	16.8	1,640	5.2	--	0.59	33.7	14.8	62.2	--	60.4	208	0.06	7.9	20.0	9.0	--	--	1.1	12	106	73.2
USGS (2011)	San Juan Basin E0709002-147	--	3.0	18.9	1,850	5.3	--	0.51	36.3	15.6	64.8	--	62.6	211	0.07	8.1	19.6	7.9	--	--	1.3	12.3	108	78.3
USGS (2011)	San Juan Basin E0709002-148	--	3.1	18.3	1,750	5.6	--	0.51	35.9	15.2	62.8	--	62.5	205	0.13	8.0	17.3	10.5	--	--	1.3	12.4	110	74.1

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Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
USGS (2011)	San Juan Basin E0709002-149	--	3.0	18.3	1,720	5.2	--	0.59	35.6	14.8	66.3	--	65.8	200	0.10	8.3	18.3	10.7	--	--	1.3	12.6	111	83.5
USGS (2011)	San Juan Basin E0709002-150	--	3.2	20.0	1,560	5.7	--	0.68	35.3	15.0	68.3	--	67.5	204	0.15	8.9	20	11.2	--	--	1.3	12.7	112	80.6
USGS (2011)	San Juan Basin E0709002-151	--	3.0	18.5	1,660	5.7	--	0.50	35.1	14.5	65.5	--	63.7	222	0.14	8.6	18.5	8.4	--	--	1.3	12.7	109	70.5
USGS (2011)	San Juan Basin E0709002-152	--	3.2	21.0	1,550	5.6	--	0.65	36.4	15.5	67.6	--	67.4	203	0.10	8.6	18.8	12.2	--	--	1.3	12.9	114	76.0
USGS (2011)	San Juan Basin E0709002-153	--	3.4	21.9	1,230	6.1	--	0.54	39.4	17.2	68.7	--	60.0	193	0.22	9.4	20.6	6.8	--	--	1.8	12.7	121	81.9
USGS (2011)	San Juan Basin E0709002-154	--	3.1	18.3	1,450	5.7	--	0.46	35.4	14.9	60.8	--	58.5	191	0.19	8.3	19.2	11.4	--	--	1.5	12.4	110	70.4
USGS (2011)	San Juan Basin E0709002-155	--	3.7	22.2	1,730	6.0	--	0.49	41.2	17.4	62.0	--	57.1	189	0.25	9.3	20.8	6.6	--	--	1.9	12.8	119	82.2
USGS (2011)	San Juan Basin E0709002-156	--	3.6	21.1	1,650	6.1	--	0.46	41.1	16.5	64.5	--	59.3	189	0.07	8.9	22.9	10.2	--	--	1.8	12.9	119	80.0
USGS (2011)	San Juan Basin E0709002-157	--	3.8	21.6	1,740	6.0	--	0.43	43.8	17.6	62.7	--	56.8	180	0.21	8.9	21.9	6.8	--	--	1.9	13	121	80.0
USGS (2011)	San Juan Basin E0709002-158	--	3.8	19.3	1,950	6.7	--	0.42	45.9	18.3	65.3	--	53.8	190	0.26	9.1	21.6	1.0	--	--	2.9	13.5	128	81.5
USGS (2011)	San Juan Basin E0709002-159	--	3.6	20.0	1,930	6.6	--	0.44	39.3	15.9	64.7	--	64.7	192	0.11	8.4	20.4	5.2	--	--	1.9	13.5	114	79.4
USGS (2011)	Appalachian Basin 7018062	--	1.4	38.4	464	8.0	--	0.6	118	27.6	193	--	41.8	228	0.03	7.2	86.4	3.9	--	--	2.4	6.5	188	98.9
USGS (2011)	Appalachian Basin 7018063	--	2.0	64.0	532	10.5	--	0.76	124	30.0	104	--	41.8	202	0.04	11.1	83	4.9	--	--	3.6	7.3	216	111
USGS (2011)	Appalachian Basin 7018064	--	1.5	48.8	546	9.1	--	0.83	122	28.2	67.7	--	34.4	207	0.03	8.3	79.5	4.3	--	--	3.2	6.8	209	96.8
USGS (2011)	Appalachian Basin 7018065	--	0.98	33.7	518	10.3	--	0.31	133	32.4	55.1	--	21.4	231	0.02	8.5	105	3.7	--	--	1.1	5.2	179	62.7
USGS (2011)	Appalachian Basin 7018066	--	1.6	52.9	570	8.9	--	0.61	128	31.6	59.4	--	33.2	242	0.03	8.9	86.6	4.2	--	--	3.1	5.9	219	95.2
USGS (2011)	Appalachian Basin 7018067	--	1.7	56.8	595	11.9	--	0.63	124	31.6	66.1	--	33.2	193	0.04	9.9	83.5	4.2	--	--	3.0	6.5	220	96.0
USGS (2011)	Appalachian Basin 7018068	--	1.7	60.3	600	12.2	--	0.66	126	32.6	72.1	--	34.8	195	0.04	10.0	87.4	4.1	--	--	3.2	6.6	229	101
USGS (2011)	Appalachian Basin 7018069	--	2.2	67.8	499	11.7	--	0.86	181	44.3	81.6	--	43.6	317	0.02	10.7	115	4.2	--	--	4.2	9.0	299	136
USGS (2011)	Appalachian Basin 7018070	--	2.0	65.6	474	13.9	--	0.84	181	46.4	90.0	--	43.7	333	0.02	10.9	123	3.7	--	--	3.7	9.6	306	126

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Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
USGS (2011)	Appalachian Basin 7018071	--	2.2	65.1	503	11.8	--	0.85	173	42.2	79.4	--	44.4	330	0.02	10.8	109	3.5	--	--	4.0	9.4	288	131
USGS (2011)	Appalachian Basin 7018072	--	2.0	61.2	497	11.0	--	0.79	162	39.0	71.1	--	41.9	285	0.02	10.6	102	3.9	--	--	3.8	9.0	270	122
USGS (2011)	Appalachian Basin 7018073	--	2.2	59.1	487	11.7	--	0.88	172	39.7	77.8	--	43.3	288	0.03	10.9	105	3.7	--	--	3.4	9.2	284	126
USGS (2011)	Appalachian Basin 7018075	--	5.3	93.8	608	15.4	--	0.96	177	43.6	90.5	--	50.4	236	0.06	18.4	108	5.5	--	--	6.1	8.6	317	141
USGS (2011)	Powder River Basin 7017049	--	1.7	20.9	3,170	2.8	--	0.70	76.4	40.9	163	--	28.2	248	0.04	5.8	154	13.1	--	--	0.60	11	240	186
USGS (2011)	Powder River Basin 7017050	--	1.7	22.0	3,370	2.9	--	0.75	85.5	43.5	171	--	29.1	188	0.02	5.9	171	12.2	--	--	0.63	11.2	258	169
USGS (2011)	Powder River Basin 7017051	--	2.1	20.0	3,140	3.1	--	0.82	79.9	39.4	143	--	29.0	159	0.13	5.9	158	11.3	--	--	0.69	9.5	293	120
USGS (2011)	Powder River Basin 7017052	--	2.0	19.0	3,160	2.8	--	0.75	79.4	36.6	140	--	27.8	242	0.12	5.7	149	12.8	--	--	0.61	8.5	297	112
USGS (2011)	Powder River Basin 7017053	--	1.9	19.2	3,180	2.7	--	0.79	80.9	37.3	141	--	27.6	244	0.51	5.6	158	13.5	--	--	0.57	8.3	309	136
USGS (2011)	Powder River Basin 7017054	--	1.9	20.9	2,980	2.7	--	0.77	84.1	37.8	139	--	26.4	213	0.77	5.6	168	13.2	--	--	0.55	8.4	317	153
USGS (2011)	Powder River Basin 7017055	--	1.9	19.2	3,170	2.6	--	0.89	82.3	36.5	140	--	26.1	252	0.69	5.9	148	11.8	--	--	0.47	8.0	315	113
USGS (2011)	Powder River Basin 7017056	--	2.0	20.0	3,260	2.8	--	0.81	88.2	41.6	156	--	29.8	229	0.70	5.8	166	11.2	--	--	0.59	8.9	341	116
USGS (2011)	Powder River Basin 7017057	--	1.9	18.6	3,170	2.5	--	0.75	81.9	36.3	144	--	27.1	207	0.70	5.3	151	12	--	--	0.54	8.0	322	112
USGS (2011)	Powder River Basin 7017058	--	2.1	19.6	3,250	2.7	--	0.90	91.5	39.4	154	--	28.9	283	0.84	5.7	165	12.9	--	--	0.59	8.5	348	147
USGS (2011)	Powder River Basin 7017059	--	2.1	20.7	3,180	2.9	--	0.85	94.4	40.8	160	--	33.1	145	0.84	6.0	167	11.8	--	--	0.62	8.7	367	165
USGS (2011)	Powder River Basin 7017060	--	2.0	20.1	3,180	2.7	--	0.89	91.6	40.8	158	--	29.4	238	0.95	5.8	170	12.1	--	--	0.59	8.3	363	118
USGS (2011)	Powder River Basin 7017061	--	1.9	14.6	3,180	2.1	--	0.83	54.1	31.4	118	--	27.2	164	0.94	5.5	106	12.4	--	--	0.61	7.4	218	87.9
USGS (2011)	Powder River Basin 7017062	--	1.7	16.3	3,110	2.4	--	0.74	82.4	35.8	138	--	25.0	256	0.97	5.0	153	12.3	--	--	0.50	7.3	321	155
USGS (2011)	Powder River Basin 7017063	--	2.0	20.0	3,110	2.9	--	0.83	102	42.7	168	--	30.9	155	0.85	6.1	180	12.7	--	--	0.75	9.2	376	138
Zhang et al. (2001)	Belews Creek	--	13.2	66.0	913	30.0	154	*< 5.5*	165	132	200	--	59.4	103	*< 0.33*	286	165	18.7	0.55	--	--	*< 11.0*	341	110

COPC = constituent of potential concern
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit

Table A-1: COPC Concentrations in Fly Ash from CCR Constituent Database (mg/kg)

Data Source	Sample ID	Aluminum	Antimony	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Manganese	Mercury	Molybdenum	Nickel	Selenium	Silver	Strontium	Thallium	Uranium	Vanadium	Zinc
Zhang et al. (2001)	Belledune	--	17.6	556	836	*< 22.0*	198	330	62.7	30.8	91.0	--	41.8	770	*< 0.33*	77	19.8	13.2	0.55	--	--	*< 11.0*	264	220
Zhang et al. (2001)	Coal Creek	--	14.3	121	5,060	*< 22.0*	946	*< 5.5*	74.8	96.8	81.0	--	20.9	627	*< 0.33*	132	60.5	14.3	0.55	--	--	*< 11.0*	165	51.7
Zhang et al. (2001)	Forestburgh	--	6.6	51.7	4,400	*< 22.0*	1,760	*< 5.5*	34.1	37.4	36.0	--	53.9	154	*< 0.33*	220	31.9	10.9	0.55	--	--	*< 11.0*	61.6	60.5
Zhang et al. (2001)	Genesee	--	5.5	*< 22.0*	3,190	*< 22.0*	396	*< 5.5*	66.0	51.7	57.0	--	29.7	308	*< 0.33*	176	36.3	4.0	0.55	--	--	*< 11.0*	132	62.7
Zhang et al. (2001)	Lingan	--	18.7	1,080	750	*< 22.0*	105	38.6	89.3	331	130	--	308	1080	*< 0.33*	220	132	4.5	0.55	--	--	*< 11.0*	209	320
Zhang et al. (2001)	Point Tupper	--	18.7	757	2,420	*< 22.0*	110	26.4	109	264	120	--	176	825	*< 0.33*	242	110	3.1	0.55	--	--	*< 11.0*	176	187
Zhang et al. (2001)	Sundance	--	9.9	28.6	3,850	*< 22.0*	583	*< 5.5*	23.1	59.4	54.0	--	52.8	528	*< 0.33*	187	42.9	2.0	0.55	--	--	*< 11.0*	75.9	48.4
Zhang et al. (2001)	Thunder Bay	--	9.9	22.0	9,020	*< 22.0*	1,430	*< 5.5*	26.4	48.4	65.0	--	46.2	100	*< 0.33*	187	36.3	9.9	0.55	--	--	*< 11.0*	82.5	24.2

COPC = constituent of potential concern

mg/kg = milligrams per kilogram

< = non-detect; value represents lowest reported detection limit

A.2.2 Department of Energy, 2008

This study collected ten samples of mined gypsum and seven samples of FGD gypsum, as well as the resulting FGD gypsum wallboard, from five different gypsum wallboard plants across the United States and analyzed these samples for mercury concentrations. The research team analyzed mercury concentrations in mined gypsum samples by cold vapor atomic fluorescence spectrometry (CV-AFS) and a separate lab analyzed mercury concentrations in FGD gypsum and the resulting wallboard samples using a DMA-80 Direct Mercury Analyzer. **Table A-2** provides the mercury data from this study.

Table A-2: Mercury Concentrations in Mined and FGD Gypsum from US Department of Energy, 2008 (mg/kg)

Sample Type*	Source Location	Mercury Concentration
Mined Gypsum	Wallboard Plant 6	0.011
Mined Gypsum	Wallboard Plant 7	0.019
Mined Gypsum	Wallboard Plant 8	0.013
Mined Gypsum	Wallboard Plant 9	0.023
Mined Gypsum	Wallboard Plant 10	0.023
Mined Gypsum	Wallboard Plant 11	*< 0.004*
Mined Gypsum	Wallboard Plant 12	0.01
Mined Gypsum	Wallboard Plant 13	0.026
Mined Gypsum	Wallboard Plant 14	*< 0.004*
Mined Gypsum	Wallboard Plant 15	*< 0.004*
Washed FGD Gypsum	Wallboard Plant 1	0.96
Washed FGD Gypsum	Wallboard Plant 1	1.1
Washed FGD Gypsum	Wallboard Plant 2	0.21
Washed FGD Gypsum	Wallboard Plant 3	0.53
Washed FGD Gypsum	Wallboard Plant 4	0.20
Washed FGD Gypsum	Wallboard Plant 4	0.13
Washed FGD Gypsum	Wallboard Plant 5	1.1
FGD Gypsum Wallboard	Wallboard Plant 1	0.95
FGD Gypsum Wallboard	Wallboard Plant 1	0.93
FGD Gypsum Wallboard	Wallboard Plant 2	0.07
FGD Gypsum Wallboard	Wallboard Plant 3	0.48
FGD Gypsum Wallboard	Wallboard Plant 4	0.12
FGD Gypsum Wallboard	Wallboard Plant 4	0.09
FGD Gypsum Wallboard	Wallboard Plant 5	0.72

FGD = flue gas desulfurization
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit
* Unwashed gypsum is FGD gypsum as generated. Washed gypsum has been treated to remove fines and impurities. FGD gypsum is typically washed prior to the production of wallboard.

A.2.3 Eckert and Guo, 1998

This study analyzed samples of portland cement for concentrations of aluminum, arsenic, chromium, cobalt, copper, lead, manganese, nickel, vanadium, and zinc. The study collected these samples from 11 cement kilns across North America that are co-fired with hazardous waste derived fuel. The research team analyzed all samples using x-ray fluoresence. **Table A-3** provides the raw data on the COPCs available from this study. When utilizing these data, the current evaluation averaged multiple data points for a single sample source into a single data point to avoid biasing the overall data set towards any single sample source. In addition, the evaluation incorporated non-detect values using half of the reported detection limit based on the recommendations in *Risk Assessment Guidance for Superfund (RAGS) Part A* (US EPA, 1989) and with *EPA Region 3 Guidance on Handling Chemical Concentration Data near the Detection Limit in Risk Assessments* (US EPA, 1991).

Table A-3: COPC Concentrations in Portland Cement from Eckert and Guo, 1998 (mg/kg)

Sample ID	Aluminum	Arsenic	Chromium	Cobalt	Copper	Lead	Manganese	Nickel	Vanadium	Zinc
Giant (SC)-1	30,273	29.0	87.0	17.0	47.0	< 5.0	77.4	52.0	136	71.0
Holnam (SC)-1	28,897	9.0	112	12.0	36.0	< 5.0	155	41.0	112	39.0
Giant (SC)-2	28,950	24.0	118	17.0	29.0	< 5.0	77.4	55.0	167	135
Holnam (SC)-2	23,816	13.0	143	9.0	86.0	< 5.0	155	49.0	114	24.0
TXI (TX)-1	23,552	10.0	315	8.0	84.0	< 5.0	1,781	49.0	108	294
TXI (TX)-2	24,981	10.0	176	8.0	83.0	< 5.0	1,317	55.0	103	332
NTXC (TX)-1	26,912	10.0	63.0	15.0	21.0	< 5.0	2,323	55.0	112	58.0
LSI (IN)-1	23,022	< 5.0	92.0	7.0	8.0	< 5.0	387	39.0	64.0	93.0
Lafarge (MI)-1	24,822	< 5.0	58.0	12.0	22.0	< 5.0	465	41.0	99.0	64.0
Holnam (MO)-1	25,087	5.0	88.0	10.0	55.0	39.0	465	47.0	95.0	239
Keystone (PA)-1	31,067	< 5.0	95.0	7.0	51.0	< 5.0	775	44.0	44.0	54.0
CCC (MO)-1	27,045	< 5.0	153	12.0	58.0	< 5.0	852	29.0	50.0	98.0
DC (TN)-1	27,151	10.0	85.0	12.0	36.0	16.0	1,162	29.0	49.0	296
RCC (MO)-1	26,251	12.0	230	7.0	198	< 5.0	2,246	57.0	149	124
Giant (SC)-3	29,056	19.0	110	19.0	63.0	140	155	91.0	125	2,522
Holnam (SC)-3	24,981	10.0	122	11.0	36.0	< 5.0	155	42.0	111	42.0

COPC = constituent of potential concern

mg/kg = milligrams per kilogram

< = non-detect; value represents lowest reported detection limit

A.2.4 Electric Power Research Institute (EPRI), 2010

EPRI submitted comments on December 17, 2010 on the 2010 Proposed CCR Disposal Rule that contained data on the concentrations of mercury in both mined gypsum and FGD gypsum. EPRI collected 32 samples of FGD gypsum, each from different power plants representing a cross-sectional sample of different coal types, power plant configurations, and management methods in use. The study did not include any samples from plants burning lignite coal. EPRI received 11 mined gypsum samples from the United States Gypsum Corporation that represented sources from across nine US states, Mexico, and Canada. All samples were prepared according to EPA Method 3051A and analyzed by inductively-coupled plasma mass spectrometry. **Table A-4** provides the mercury summary statistics available from this study.

Table A-4: Mercury Concentration in FGD and Mined Gypsum from EPRI, 2010 (mg/kg)

Sample Type	Sample Number	Minimum	10th Percentile	Median	90th Percentile	Maximum
Mined Gypsum	11	0.0003	0.0005	0.0007	0.0100	0.0151
FGD Gypsum	32	0.007	0.035	0.194	0.660	1.41

FGD = flue gas desulfurization
mg/kg = milligrams per kilogram

A.2.5 Garrabrants et al., 2013

This study collected four fly ashes that are commercially marketed for beneficial use in concrete. Researchers used these fly ashes to create three sets of concrete for analysis. The first and second sets were concrete with a 20 percent and 45 percent fly ash replacement, respectively, using three of the fly ashes. The third set was micro-concrete with a 45 percent fly ash replacement, using all four fly ashes. Each set had a single corresponding sample made with only portland cement. This study allowed the concrete to cure for three months prior to sampling and then collected concrete leachate according to EPA LEAF Method 1315. The research team collected leachate at nine different time points beginning at 0.08 days and ending at 63 days and analyzed it for various constituents, including antimony, arsenic, boron, cadmium, chromium, lead, molybdenum, selenium, and thallium. This study analyzed boron by EPA Method 6010C and analyzed the other constituents by EPA Method 6020A. Researchers conducted QA/QC according to the methods outlined in US EPA (2012). **Table A-5** provides the raw data on COPCs available from this study.

Table A-5: Mass Transfer Leachate Concentrations from Portland Cement and Fly Ash Concretes from Garrabrants et al., 2013 (mg/m^2)

COPC	Sample ID	Sample Type	Ash Replacement Rate (Percent)	Time Step (Days)								
				0.08	1	2	7	14	28	42	49	63
Antimony	C-20-00-3m	Concrete	0	< 0.008	< 0.016	< 0.024	< 0.032	0.041	0.053	0.067	0.077	0.087
Antimony	C-20-02-3m	Concrete	20	< 0.008	< 0.016	< 0.024	< 0.032	0.042	0.056	0.068	0.078	0.089
Antimony	C-20-18-3m	Concrete	20	< 0.008	< 0.016	< 0.024	< 0.032	< 0.040	0.049	0.060	0.068	0.078
Antimony	C-20-39-3m	Concrete	20	< 0.008	< 0.016	< 0.024	< 0.032	< 0.040	0.049	0.060	0.068	0.078
Antimony	C-45-00-3m	Concrete	0	< 0.008	< 0.016	< 0.024	< 0.032	0.041	0.054	0.070	0.085	0.096
Antimony	C-45-02-3m	Concrete	45	< 0.008	< 0.016	< 0.024	< 0.032	0.042	0.058	0.075	0.093	0.104
Antimony	C-45-18-3m	Concrete	45	< 0.008	< 0.016	< 0.024	< 0.032	< 0.040	< 0.048	0.057	0.064	< 0.071
Antimony	C-45-39-3m	Concrete	45	< 0.008	< 0.016	< 0.024	< 0.032	< 0.040	0.050	0.060	0.067	0.078
Antimony	M-45-00-3m	Micro-Concrete	0	< 0.008	< 0.016	< 0.024	0.033	0.048	0.065	0.081	0.095	0.109
Antimony	M-45-02-3m	Micro-Concrete	45	< 0.008	0.017	0.025	0.045	0.065	0.089	0.111	0.126	0.147
Antimony	M-45-18-3m	Micro-Concrete	45	< 0.008	< 0.016	< 0.024	0.032	0.044	0.059	0.072	0.082	0.094
Antimony	M-45-39-3m	Micro-Concrete	45	< 0.008	< 0.016	< 0.024	< 0.032	0.043	0.057	0.069	0.078	0.090
Antimony	M-45-FaFA-3m	Micro-Concrete	45	< 0.008	0.027	0.045	0.081	0.119	0.159	0.192	0.219	0.239
Arsenic	C-20-00-3m	Concrete	0	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	C-20-02-3m	Concrete	20	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	C-20-18-3m	Concrete	20	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	C-20-39-3m	Concrete	20	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	C-45-00-3m	Concrete	0	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	C-45-02-3m	Concrete	45	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	C-45-18-3m	Concrete	45	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	C-45-39-3m	Concrete	45	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	M-45-00-3m	Micro-Concrete	0	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	M-45-02-3m	Micro-Concrete	45	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	M-45-18-3m	Micro-Concrete	45	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	M-45-39-3m	Micro-Concrete	45	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Arsenic	M-45-FaFA-3m	Micro-Concrete	45	< 0.064	< 0.128	< 0.192	< 0.256	< 0.320	< 0.384	< 0.448	< 0.512	< 0.576
Boron	C-20-00-3m	Concrete	0	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	C-20-02-3m	Concrete	20	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	C-20-18-3m	Concrete	20	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	C-20-39-3m	Concrete	20	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	C-45-00-3m	Concrete	0	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	C-45-02-3m	Concrete	45	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	C-45-18-3m	Concrete	45	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	C-45-39-3m	Concrete	45	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	M-45-00-3m	Micro-Concrete	0	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	M-45-02-3m	Micro-Concrete	45	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	M-45-18-3m	Micro-Concrete	45	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	M-45-39-3m	Micro-Concrete	45	< 0.100	< 0.200	< 0.300	< 0.400	< 0.500	< 0.600	< 0.700	< 0.800	< 0.900
Boron	M-45-FaFA-3m	Micro-Concrete	45	< 0.100	< 0.200	0.336	0.69	1.01	1.223	1.423	1.541	1.645

COPC = constituent of potential concern
mg/m^2 = milligrams per square meter
< = non-detect; value represents lowest reported detection limit

Table A-5: Mass Transfer Leachate Concentrations from Portland Cement and Fly Ash Concretes from Garrabrants et al., 2013 (mg/m^2)

COPC	Sample ID	Sample Type	Ash Replacement Rate (Percent)	Time Step (Days)								
				0.08	1	2	7	14	28	42	49	63
Cadmium	C-20-00-3m	Concrete	0	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	C-20-02-3m	Concrete	20	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	C-20-18-3m	Concrete	20	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	C-20-39-3m	Concrete	20	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	C-45-00-3m	Concrete	0	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	C-45-02-3m	Concrete	45	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	C-45-18-3m	Concrete	45	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	C-45-39-3m	Concrete	45	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	M-45-00-3m	Micro-Concrete	0	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	M-45-02-3m	Micro-Concrete	45	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	M-45-18-3m	Micro-Concrete	45	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	M-45-39-3m	Micro-Concrete	45	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Cadmium	M-45-FaFA-3m	Micro-Concrete	45	< 0.017	< 0.034	< 0.051	< 0.068	< 0.086	< 0.103	< 0.120	< 0.137	< 0.154
Chromium	C-20-00-3m	Concrete	0	< 0.050	< 0.099	< 0.149	< 0.199	0.290	0.401	0.504	0.563	0.614
Chromium	C-20-02-3m	Concrete	20	< 0.050	< 0.099	< 0.149	< 0.199	< 0.249	0.329	0.401	0.445	0.497
Chromium	C-20-18-3m	Concrete	20	< 0.050	0.108	0.171	0.26	0.377	0.483	0.586	0.654	0.742
Chromium	C-20-39-3m	Concrete	20	< 0.050	0.148	0.216	0.283	0.395	0.53	0.84	0.908	0.985
Chromium	C-45-00-3m	Concrete	0	< 0.050	< 0.099	< 0.149	< 0.199	0.336	0.452	0.591	0.694	0.741
Chromium	C-45-02-3m	Concrete	45	< 0.050	< 0.099	< 0.149	< 0.199	< 0.249	< 0.298	< 0.348	< 0.398	< 0.447
Chromium	C-45-18-3m	Concrete	45	< 0.050	< 0.099	< 0.149	0.238	0.43	0.552	0.644	0.693	0.765
Chromium	C-45-39-3m	Concrete	45	< 0.050	< 0.099	< 0.149	0.258	0.363	0.478	0.571	0.617	0.706
Chromium	M-45-00-3m	Micro-Concrete	0	< 0.050	< 0.099	0.157	0.353	0.55	0.735	0.888	0.981	1.085
Chromium	M-45-02-3m	Micro-Concrete	45	< 0.050	< 0.099	< 0.149	< 0.199	0.25	0.321	0.374	0.416	0.458
Chromium	M-45-18-3m	Micro-Concrete	45	< 0.050	0.125	0.17	0.303	0.515	0.695	0.827	0.895	0.967
Chromium	M-45-39-3m	Micro-Concrete	45	< 0.050	< 0.099	< 0.149	0.278	0.443	0.559	0.662	0.743	0.833
Chromium	M-45-FaFA-3m	Micro-Concrete	45	0.067	0.204	0.298	0.492	0.663	0.838	0.964	1.048	1.123
Lead	C-20-00-3m	Concrete	0	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	C-20-02-3m	Concrete	20	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	C-20-18-3m	Concrete	20	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	C-20-39-3m	Concrete	20	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	C-45-00-3m	Concrete	0	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	C-45-02-3m	Concrete	45	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	C-45-18-3m	Concrete	45	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	C-45-39-3m	Concrete	45	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	M-45-00-3m	Micro-Concrete	0	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	M-45-02-3m	Micro-Concrete	45	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	M-45-18-3m	Micro-Concrete	45	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	M-45-39-3m	Micro-Concrete	45	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205
Lead	M-45-FaFA-3m	Micro-Concrete	45	< 0.023	< 0.046	< 0.068	< 0.091	< 0.114	< 0.137	< 0.160	< 0.182	< 0.205

COPC = constituent of potential concern
mg/m^2 = milligrams per square meter
< = non-detect; value represents lowest reported detection limit

Table A-5: Mass Transfer Leachate Concentrations from Portland Cement and Fly Ash Concretes from Garrabrants et al., 2013 (mg/m^2)

COPC	Sample ID	Sample Type	Ash Replacement Rate (Percent)	Time Step (Days)								
				0.08	1	2	7	14	28	42	49	63
Molybdenum	C-20-00-3m	Concrete	0	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	C-20-02-3m	Concrete	20	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	C-20-18-3m	Concrete	20	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	C-20-39-3m	Concrete	20	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	C-45-00-3m	Concrete	0	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	C-45-02-3m	Concrete	45	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	C-45-18-3m	Concrete	45	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	C-45-39-3m	Concrete	45	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	M-45-00-3m	Micro-Concrete	0	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	M-45-02-3m	Micro-Concrete	45	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	M-45-18-3m	Micro-Concrete	45	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	M-45-39-3m	Micro-Concrete	45	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Molybdenum	M-45-FaFA-3m	Micro-Concrete	45	*< 0.076*	*< 0.152*	*< 0.228*	*< 0.304*	*< 0.380*	*< 0.455*	*< 0.531*	*< 0.607*	*< 0.683*
Selenium	C-20-00-3m	Concrete	0	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	C-20-02-3m	Concrete	20	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	C-20-18-3m	Concrete	20	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	C-20-39-3m	Concrete	20	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	C-45-00-3m	Concrete	0	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	C-45-02-3m	Concrete	45	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	C-45-18-3m	Concrete	45	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	C-45-39-3m	Concrete	45	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	M-45-00-3m	Micro-Concrete	0	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	M-45-02-3m	Micro-Concrete	45	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	M-45-18-3m	Micro-Concrete	45	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	M-45-39-3m	Micro-Concrete	45	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Selenium	M-45-FaFA-3m	Micro-Concrete	45	*< 0.052*	*< 0.104*	*< 0.156*	*< 0.208*	*< 0.26*	*< 0.312*	*< 0.364*	*< 0.416*	*< 0.468*
Thallium	C-20-00-3m	Concrete	0	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	C-20-02-3m	Concrete	20	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	C-20-18-3m	Concrete	20	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	C-20-39-3m	Concrete	20	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	C-45-00-3m	Concrete	0	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	C-45-02-3m	Concrete	45	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	C-45-18-3m	Concrete	45	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	C-45-39-3m	Concrete	45	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	M-45-00-3m	Micro-Concrete	0	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	M-45-02-3m	Micro-Concrete	45	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	M-45-18-3m	Micro-Concrete	45	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	M-45-39-3m	Micro-Concrete	45	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*
Thallium	M-45-FaFA-3m	Micro-Concrete	45	*< 0.051*	*< 0.101*	*< 0.152*	*< 0.202*	*< 0.253*	*< 0.304*	*< 0.354*	*< 0.405*	*< 0.455*

COPC = constituent of potential concern
mg/m^2 = milligrams per square meter
< = non-detect; value represents lowest reported detection limit

A.2.6 Golightly et al., 2005

This study measured the rate of mercury emanation from three concrete samples. The study produced these samples using pure portland cement, portland cement with a 33 percent fly ash replacement rate, or portland cement with a 55 percent fly ash replacement rate. The researchers poured each concrete mixture into an air-tight container and collected samples of emitted mercury from the container as the cement cured. Using a three-step process, the study collected three to six samples for each type of concrete. First, researchers pumped ambient air through an iodated carbon trap to remove any mercury already present in the ambient air. Next, they pumped the purified air through one of the containers to entrain any mercury vapor emitted by the concrete. Finally, they pumped the air through a second iodated carbon trap to capture all of the mercury emitted by the concrete. The study pumped air continuously across the concrete during the first two days of curing, after which researchers removed the iodated carbon traps for analysis. The research team replaced the iodated carbon traps and repeated the sampling process for an additional 26 days. For some concrete samples, the study repeated this process again for an additional 28 days. For each concrete sample collected, researchers collected a corresponding blank sample using the same sampling process but without any concrete present in the containers. The research team analyzed all concrete and blank samples using cold vapor-atomic fluorescence spectrometry (CV-AFS). Following analysis, researchers subtracted the mercury concentrations measured in the blank samples from those measured in the corresponding concrete samples prior to reporting.

Table A-6 provides average reported results of the samples for 28 and 56 day curing times. While a 55 percent fly ash replacement rate falls outside the scope of the current evaluation, this data was retained in the evaluation to capture a conservative upper bound of potential releases. Golightly et al. (2005) reported sample concentrations in nanograms per kilogram-day (ng/kg-day). This evaluation converted concentrations to ng/m^2-hr by multiplying reported release rates by the mass of the samples (65 kg), dividing by the concrete surface area (0.062 m^2), and making necessary unit conversions.

Table A-6: Mercury Emanation Rates for Fly Ash and Portland Cement Concretes from Golightly et al., 2005

Concrete			28-Day Mercury Releases Sampling Duration - 28 Days		56-Day Mercury Releases Sampling Duration - 28 Days	
Fly Ash (Percent)	Sample ID	Average Concentration (µg/kg)	N	Release Rate (ng/kg-day)	N	Release Rate (ng/kg-day)
0	OPC	4.1	4	0.10 ± 0.03	2	0.08 ± 0.05
33	FA33	9.2	6	0.26 ± 0.04	--	--
55	FA55	12.6	3	0.34 ± 0.09	1	0.10

N = number of samples
µg/kg-day = micrograms per kilogram-day

The study also measured releases following a two-day cure time. These data are not considered representative of potential residential exposures because a building with such newly poured concrete is unlikely to be habitable. Therefore, these results are not included in the table above. The study also evaluated concrete made with fly ashes containing activated carbon. Although these fly ashes met ASTM requirements for loss of ignition (LOI; ASTM Standard C618), this type of ash represents a pollution control technology that is outside the scope of this document. Therefore, the current evaluation did not retain these data for further evaluation.

A.2.7 Golightly et al., 2009

This study measured the rate of mercury emanation from three concrete samples. The study produced these samples using pure portland cement or portland cement with a 55 percent fly ash replacement rate. The researchers poured each concrete mixture into an air-tight container and collected samples of emitted mercury into the container as it cured. Using a three-step process, the study collected triplicate samples from each concrete. First, researchers pumped ambient air through an iodated carbon trap to remove any mercury already present in the ambient air. Next, they pumped the purified air through one of the containers to entrain any mercury vapor emitted by the concrete. Finally, they pumped the air through a second iodated carbon trap to capture all of the mercury emitted by the concrete. The study pumped air continuously across the concrete during the first 28 days of curing, after which researchers removed the iodated carbon traps for analysis. For one fly ash concrete sample, the research team replaced the iodated carbon trap and the sampling process was repeated four additional times, each with a duration of seven days. For each concrete sample collected, researchers collected a corresponding blank sample using the same sampling process, but without any concrete present in the containers. The research team analyzed all samples using CV-AFS. Following analysis, researchers subtracted the mercury concentrations measured in the blank samples from those measured in the corresponding concrete samples prior to reporting.

Table A-7 provides the average results reported for each set of triplicate samples. While a 55 percent fly ash replacement rate falls outside the scope of the current evaluation, this data was retained in the evaluation to capture a conservative upper bound of potential releases. Golightly et al. (2009) reported sample concentrations in nanograms per trap (ng/trap). This evaluation converted the concentrations to nanograms per meter squared-hour (ng/m^2-hr) by dividing measured release rates by the duration of sampling (168 or 672 hours) and the surface area of the concrete (0.062 m^2).

Table A-7: Mercury Emanation Rates for Fly Ash and Portland Cement Concrete from Golightly et al., 2009

Initial Concrete			28-Day Mercury Releases Sampling Duration - 28 Days			56-Day Mercury Releases Sampling Duration 7 Days		
Fly Ash (Percent)	Sample ID	Average Conc. (µg/kg)	N	Average Conc. (ng/trap)	Standard Deviation	N	Average Conc. (ng/trap)	Standard Deviation
0	OPC	5.2	3	116.0	± 15.3	--	--	--
55	CCS1	5.6	3	343.6	± 50.5	--	--	--
55	MER032	30.4	3	1,447.8	± 77.1	3	162.1	± 44.4

N = number of samples

µg/kg = micrograms per kilogram

ng/trap = nanograms per trap

The study also evaluated concrete made with fly ashes containing activated carbon. Although these fly ashes met ASTM requirements for LOI (ASTM Standard C618), this type of ash represents a pollution control technology that is outside the scope of this document. Therefore, the current evaluation did not retain these data for further evaluation.

A.2.8 Gypsum Association, 2010

The Gypsum Association submitted comments on November 19, 2010 to the docket of the 2010 Proposed CCR Disposal Rule that contained data on the concentration of metals in both mined gypsum and FGD gypsum. The Gypsum Association worked in conjunction with ARCADIS U.S., Inc. (a consultant to the Gypsum Association) to review and report available data from multiple sources on mercury concentrations in mined gypsum, unwashed FGD gypsum, and washed FGD gypsum. These comments did not provide information on the method of collection or analysis for these samples. **Table A-8** presents the maximum mercury concentrations from this study. The Gypsum Association only provided data on the maximum concentrations detected and did not provide data on the number of samples analyzed.

Table A-8: Mercury Concentrations in FGD and Mined Gypsum from Gypsum Association, 2010 (mg/kg)

Types of Sample*	Maximum Concentration
Mined Gypsum	0.0844
FGD Gypsum	0.95

FGD = flue gas desulfurization
mg/kg = milligrams per kilogram
* Unwashed gypsum is FGD gypsum as generated. Washed gypsum has been treated to remove fines and impurities. FGD gypsum is typically washed prior to the production of wallboard.

A.2.9 Kairies et al., 2006

This study analyzed five samples of FGD gypsum and the resulting FGD gypsum wallboard for mercury concentrations. Researchers collected samples from five different wallboard manufacturing plants and analyzed mercury concentrations by cold vapor atomic adsorption. This study collected quality assurance/quality control (QA/QC) samples according to EPA Method 1631, Revision B. **Table A-9** provides the mercury data reported in this study.

Table A-9: Mercury Concentrations in FGD Gypsum from Kairies et al., 2006 (mg/kg)

Types of Sample	Plant A	Plant B	Plant C	Plant D	Plant E
FGD Gypsum	0.14 ± 0.004	0.25 ± 0.007	1.22 ± 0.051	1.46 ± 0.050	0.49 ± 0.016
FGD Gypsum Wallboard	0.15 ± 0.002	0.11 ± 0.005	1.28 ± 0.063	1.37 ± 0.059	0.42 ± 0.003

FGD = flue gas desulfurization
mg/kg = milligrams per kilogram

A.2.10 Kosson et al., 2013

This study collected four fly ashes that are commercially marketed for beneficial use in concrete. Researchers used these fly ashes to create three sets of concretes for analysis. The first and second sets were concrete with a 20 percent and 45 percent fly ash replacement, respectively, using three of the fly ashes. The third set was micro-concrete with a 45 percent fly ash replacement, using all four fly ashes. Each set had a single corresponding sample made with only portland cement. This study collected concrete leachate according to EPA LEAF Method 1313. The research team analyzed leachate for various constituents, including antimony, arsenic, boron, cadmium, chromium, lead, molybdenum, selenium, and thallium. This study analyzed boron using EPA Method 6010C and the other constituents by EPA Method 6020A. This study conducted QA/QC according to the methods outlined in US EPA (2012). The researchers calculated the leachable content by taking the mean of the maximum measured values over the entire pH range and multiplying it by the liquid to solid (L/S) ratio of 10 L/kg. Although this study collected data over a pH range of 2 to 13, not all of these data are relevant to the current evaluation. Based on the theoretical pH range of concretes, this evaluation only considered data in the pH range of 7 to 13, and selected the maximum reported leachate concentration reported over this pH range as an appropriate bounding for the current evaluation. **Table A-10** provides the maximum values reported for the two sample sets made with 45 percent fly ash replacement.

Table A-10: Liquid-Solid Partitioning Data from Portland Cement Concrete and Fly Ash Concrete from Kosson et al., 2013

COPC	Sample ID	Sample Type	Ash Replacement Rate (percent)	Maximum Leachate Concentration (µg/L)	Available Content (mg/kg)
Antimony	C-45-00-3m	Concrete	0	8.0	0.65
Antimony	C-45-02-3m	Concrete	45	14.0	0.51
Antimony	C-45-18-3m	Concrete	45	14.0	0.51
Antimony	C-45-39-3m	Concrete	45	10.0	0.48
Antimony	M-45-00-3m	Micro-Concrete	0	22.0	0.42
Antimony	M-45-02-3m	Micro-Concrete	45	12.0	0.29
Antimony	M-45-18-3m	Micro-Concrete	45	12.0	0.18
Antimony	M-45-39-3m	Micro-Concrete	45	20.0	0.22
Antimony	M-45-FaFA-3m	Micro-Concrete	45	11.0	0.25
Arsenic	C-45-00-3m	Concrete	0	11.0	1.7
Arsenic	C-45-02-3m	Concrete	45	14.0	4.2
Arsenic	C-45-18-3m	Concrete	45	19.0	2.4
Arsenic	C-45-39-3m	Concrete	45	18.0	2.3
Arsenic	M-45-00-3m	Micro-Concrete	0	34.0	0.89
Arsenic	M-45-02-3m	Micro-Concrete	45	13.0	2.2
Arsenic	M-45-18-3m	Micro-Concrete	45	29.0	1.1
Arsenic	M-45-39-3m	Micro-Concrete	45	25.0	1.2
Arsenic	M-45-FaFA-3m	Micro-Concrete	45	23.0	1.2

COPC = constituent of potential concern
µg/L = micrograms per liter
mg/kg = milligrams per kilogram

Table A-10: Liquid-Solid Partitioning Data from Portland Cement Concrete and Fly Ash Concrete from Kosson et al., 2013

COPC	Sample ID	Sample Type	Ash Replacement Rate (percent)	Maximum Leachate Concentration (µg/L)	Available Content (mg/kg)
Boron	C-45-00-3m	Concrete	0	140	7.0
Boron	C-45-02-3m	Concrete	45	780	21.0
Boron	C-45-18-3m	Concrete	45	1,000	22.0
Boron	C-45-39-3m	Concrete	45	1,000	31.0
Boron	M-45-00-3m	Micro-Concrete	0	560	10.0
Boron	M-45-02-3m	Micro-Concrete	45	3,200	32.0
Boron	M-45-18-3m	Micro-Concrete	45	3,200	32.0
Boron	M-45-39-3m	Micro-Concrete	45	2,300	44.0
Boron	M-45-FaFA-3m	Micro-Concrete	45	800	10.0
Cadmium	C-45-00-3m	Concrete	0	*< 0.20*	0.17
Cadmium	C-45-02-3m	Concrete	45	*< 0.20*	0.11
Cadmium	C-45-18-3m	Concrete	45	*< 0.20*	0.16
Cadmium	C-45-39-3m	Concrete	45	*< 0.20*	0.18
Cadmium	M-45-00-3m	Micro-Concrete	0	1.7	0.29
Cadmium	M-45-02-3m	Micro-Concrete	45	0.50	0.22
Cadmium	M-45-18-3m	Micro-Concrete	45	0.80	0.16
Cadmium	M-45-39-3m	Micro-Concrete	45	0.60	0.16
Cadmium	M-45-FaFA-3m	Micro-Concrete	45	1.0	0.10
Chromium	C-45-00-3m	Concrete	0	100	9.3
Chromium	C-45-02-3m	Concrete	45	83.0	7.2
Chromium	C-45-18-3m	Concrete	45	130	7.8
Chromium	C-45-39-3m	Concrete	45	120	7.6
Chromium	M-45-00-3m	Micro-Concrete	0	1,100	15.0
Chromium	M-45-02-3m	Micro-Concrete	45	170	6.8
Chromium	M-45-18-3m	Micro-Concrete	45	560	13.0
Chromium	M-45-39-3m	Micro-Concrete	45	780	13.0
Chromium	M-45-FaFA-3m	Micro-Concrete	45	460	7.4
Lead	C-45-00-3m	Concrete	0	2.0	3.0
Lead	C-45-02-3m	Concrete	45	1.2	2.0
Lead	C-45-18-3m	Concrete	45	1.8	1.4
Lead	C-45-39-3m	Concrete	45	2.9	2.5
Lead	M-45-00-3m	Micro-Concrete	0	2.1	0.03
Lead	M-45-02-3m	Micro-Concrete	45	2.0	0.66
Lead	M-45-18-3m	Micro-Concrete	45	2.6	0.21
Lead	M-45-39-3m	Micro-Concrete	45	2.8	0.20
Lead	M-45-FaFA-3m	Micro-Concrete	45	7.5	1.8

COPC = constituent of potential concern
µg/L = micrograms per liter
mg/kg = milligrams per kilogram

Table A-10: Liquid-Solid Partitioning Data from Portland Cement Concrete and Fly Ash Concrete from Kosson et al., 2013

COPC	Sample ID	Sample Type	Ash Replacement Rate (percent)	Maximum Leachate Concentration (µg/L)	Available Content (mg/kg)
Molybdenum	C-45-00-3m	Concrete	0	9.0	0.29
Molybdenum	C-45-02-3m	Concrete	45	47.0	0.51
Molybdenum	C-45-18-3m	Concrete	45	27.0	0.37
Molybdenum	C-45-39-3m	Concrete	45	23.0	0.47
Molybdenum	M-45-00-3m	Micro-Concrete	0	15.0	0.15
Molybdenum	M-45-02-3m	Micro-Concrete	45	0.45	0.45
Molybdenum	M-45-18-3m	Micro-Concrete	45	0.38	0.38
Molybdenum	M-45-39-3m	Micro-Concrete	45	0.50	0.51
Molybdenum	M-45-FaFA-3m	Micro-Concrete	45	0.37	0.37
Selenium	C-45-00-3m	Concrete	0	22.0	0.84
Selenium	C-45-02-3m	Concrete	45	14.0	0.67
Selenium	C-45-18-3m	Concrete	45	24.0	0.80
Selenium	C-45-39-3m	Concrete	45	21.0	0.78
Selenium	M-45-00-3m	Micro-Concrete	0	38.0	0.41
Selenium	M-45-02-3m	Micro-Concrete	45	48.0	0.48
Selenium	M-45-18-3m	Micro-Concrete	45	42.0	0.42
Selenium	M-45-39-3m	Micro-Concrete	45	42.0	0.67
Selenium	M-45-FaFA-3m	Micro-Concrete	45	19.0	0.20
Thallium	C-45-00-3m	Concrete	0	*< 0.50*	0.09
Thallium	C-45-02-3m	Concrete	45	1.3	0.23
Thallium	C-45-18-3m	Concrete	45	*< 0.50*	0.04
Thallium	C-45-39-3m	Concrete	45	*< 0.50*	0.04
Thallium	M-45-00-3m	Micro-Concrete	0	3.0	0.12
Thallium	M-45-02-3m	Micro-Concrete	45	2.0	0.11
Thallium	M-45-18-3m	Micro-Concrete	45	3.0	0.14
Thallium	M-45-39-3m	Micro-Concrete	45	*< 0.50*	0.10
Thallium	M-45-FaFA-3m	Micro-Concrete	45	1.0	0.11

COPC = constituent of potential concern
µg/L = micrograms per liter
mg/kg = milligrams per kilogram

A.2.11 PCA, 1992

This study analyzed samples of portland cement for concentrations of antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver, and thallium. This study collected samples from 94 cement kilns across North America and analyzed each COPC according to EPA 7000 Series Methods corresponding to each individual constituent. **Table A-11** provides the raw data on the COPCs available from this study. When utilizing these data, the current evaluation incorporated non-detect values using half of the reported detection limit based on the recommendations in *Risk Assessment Guidance for Superfund (RAGS) Part A* (US EPA, 1989) and with *EPA Region 3 Guidance on Handling Chemical Concentration Data near the Detection Limit in Risk Assessments* (US EPA, 1991).

Table A-11: COPC Concentrations in Portland Cement from Portland Cement Association, 1992 (mg/kg)

Sample ID	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Lead	Mercury	Nickel	Selenium	Silver	Thallium
1	*< 0.19*	15.0	455	0.85	*< 0.05*	37.5	2.9	*< 0.014*	29.0	*< 9.0*	9.7	0.22
2	0.69	50.4	392	0.70	*< 0.05*	27.6	11.3	0.02	*< 10.0*	*< 4.0*	6.9	0.83
3	*< 0.19*	*< 25.4*	339	0.83	*< 0.05*	40.7	*< 0.4*	*< 0.086*	28.0	*< 4.0*	11.8	0.86
4	*< 0.19*	20	572	0.96	0.79	72.3	8.5	*< 0.01*	55.0	*< 7.0*	8.3	*< 0.1*
5.1	*< 0.19*	12.5	184	1.6	*< 0.05*	63.2	6.5	0.01	45.0	*< 3.0*	7.7	0.88
5.2	*< 0.19*	*< 30.4*	168	1.6	0.14	50.8	9.1	*< 0.104*	45.0	*< 3.0*	8.1	*< 1*
6	*< 0.19*	*< 16.1*	166	1.3	*< 0.05*	46	7.2	*< 0.104*	18.0	*< 0.9*	9.2	*< 0.1*
7	3.97	13.4	206	1.6	*< 0.079*	144	7.0	*< 0.104*	129	1.7	9.0	*< 0.1*
8	*< 0.19*	16.8	279	1.9	*< 0.05*	51.6	5.2	*< 0.004*	42.0	*< 6.0*	*< 0.7*	2.66
9	*< 0.19*	*< 10.0*	157	0.63	0.52	80.5	20.6	0.01	28.0	*< 4.0*	8.7	0.45
10	*< 0.19*	*< 25.4*	217	1.4	0.36	70.5	11.1	*< 0.086*	23.0	*< 4.0*	12.2	*< 0.8*
11	*< 0.19*	16.5	220	2.4	*< 0.05*	38	3.4	*< 0.004*	13.0	*< 4.0*	12.5	*< 0.6*
12	*< 0.19*	31.3	242	0.74	0.3	79.8	74.8	*< 0.148*	37.0	*< 4.0*	8.2	*< 1.0*
13	*< 0.19*	21.3	84.3	0.32	1.07	67.1	5.5	*< 0.004*	102	*< 4.0*	10.6	*< 0.6*
14	*< 0.19*	*< 22.6*	225	0.59	*< 0.03*	131	16.6	*< 0.004*	24.0	*< 3.0*	11.6	*< 0.4*
15	*< 0.19*	*< 25.4*	224	1.1	0.76	99.5	18.3	*< 0.086*	20.0	*< 2.0*	8.8	0.45
16	*< 0.19*	*< 16.0*	174	0.67	*< 0.05*	46.6	*< 5*	*< 0.062*	26.0	*< 3.0*	8.0	*< 0.5*
17	*< 0.19*	12.2	149	0.83	0.04	79.1	15.0	*< 0.014*	22.0	*< 4.0*	9.3	*< 1.0*
18.1	*< 0.19*	44.3	777	1.4	*< 0.15*	53.4	12.0	*< 0.014*	32.0	*< 4.0*	8.9	0.53

COPC = constituent of potential concern
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit

Table A-11: COPC Concentrations in Portland Cement from Portland Cement Association, 1992 (mg/kg)

Sample ID	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Lead	Mercury	Nickel	Selenium	Silver	Thallium
18.2	< 0.19	35.1	737	1.9	0.066	61.3	13.7	< 0.014	30.0	1.4	9.1	< 2.0
19	< 0.19	9.19	184	0.87	< 0.05	58.6	4.9	< 0.014	< 10.0	< 4.0	9.3	< 0.7
20	< 0.19	14.2	165	0.67	< 0.05	33.3	6.9	0.016	10.0	< 2.0	7.7	< 0.6
21	< 0.19	10.2	164	0.77	< 0.05	214	3.3	< 0.014	24.0	< 4.0	9.1	1.16
22	< 0.19	< 16.0	1170	1.7	0.47	64	9.3	< 0.062	< 19.0	< 4.0	9.5	0.04
23	< 0.19	27.5	242	0.56	0.17	41.5	17.2	< 0.004	14.0	< 3.0	9.0	< 1.0
24	< 0.19	< 12.0	148	0.35	0.23	50.9	4.3	< 0.062	< 2.0	< 4.0	7.1	< 0.4
25	< 0.19	29.6	252	0.81	0.18	73.6	7.8	< 0.15	17.0	< 4.0	8.0	0.01
26	< 0.19	< 16.0	1150	2.1	0.61	52.3	8.1	< 0.062	20.0	< 4.0	8.2	< 0.5
27	< 0.19	< 16.0	92.9	1.1	< 0.05	33.8	8.1	< 0.062	23.0	< 3.0	7.6	< 0.4
28	< 0.19	22.3	182	1.0	< 0.03	38.6	8.6	< 0.014	11.0	< 1.0	9.1	< 0.4
29	< 0.19	23.0	178	1.4	< 0.05	128	14.6	< 0.15	51.0	< 6.0	9.8	< 0.4
30	< 0.19	< 25.4	181	1.4	0.39	38.7	5.9	< 0.086	< 24.0	< 4.0	6.8	< 0.4
31	< 0.19	< 9.8	156	0.52	< 0.05	27.1	6.9	< 0.15	34.0	< 3.0	8.0	< 0.4
33	< 0.19	< 25.4	123	0.81	< 0.05	38.4	8.0	< 0.086	22.0	< 11.0	7.9	1.45
34	< 0.64	27.4	376	2.8	< 0.05	50.1	4.2	< 0.004	22.0	< 4.0	15.8	1.24
35	< 0.19	< 12.0	213	0.96	0.2	43.1	23.2	< 0.062	15.0	< 4.0	7.2	< 0.2
36	< 0.19	< 8.0	172	1.1	< 0.01	54.9	5.5	0.014	18.0	< 0.7	8.2	0.77
37	< 0.19	< 9.8	389	1.3	< 0.05	45.2	10.0	< 0.15	17.0	< 2.0	8.5	< 0.2
38	< 0.19	9.8	204	0.89	< 0.05	92.7	< 1.0	< 0.15	39.0	< 1.0	10.2	< 0.3
39	< 0.19	20.6	312	0.89	< 0.05	58.3	2.5	< 0.004	12.0	< 6.0	8.5	2.68
40	< 0.19	< 14.6	159	0.68	< 0.05	38.6	3.8	< 0.004	< 11.0	< 5.0	9.4	< 0.9
41.1	< 0.19	10.1	214	0.73	0.51	27.0	10.0	< 0.014	16.0	< 4.0	10.1	0.43
41.2	< 0.19	< 17.3	265	0.79	0.052	26.4	3.7	< 0.014	11.0	< 0.7	13.6	< 1
42	< 0.19	< 9.8	494	0.90	< 0.05	422	< 1.0	< 0.15	52.0	< 3.0	12.0	< 0.2
43	< 0.19	15.2	548	1.3	< 0.05	198	11.4	< 0.15	36.0	< 4.0	14.1	< 0.2

COPC = constituent of potential concern
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit

Table A-11: COPC Concentrations in Portland Cement from Portland Cement Association, 1992 (mg/kg)

Sample ID	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Lead	Mercury	Nickel	Selenium	Silver	Thallium
44.1	< 0.19	< 25.4	172	0.63	0.38	96.5	12.0	< 0.086	23.0	< 5.0	10.6	0.41
45	< 0.19	29.1	177	1.2	0.26	82.7	< 11.0	< 0.062	32.0	< 2.0	9.0	< 0.2
46	< 0.19	< 16.0	200	0.71	0.81	113	4.7	< 0.062	37.0	< 2.0	7.5	< 0.2
47	< 0.19	< 29.0	160	1.2	< 0.05	57.7	2.9	< 0.007	36.0	1.1	7.6	< 0.2
48	< 0.19	14.2	294	2.9	< 0.05	42.2	2.5	0.017	30.0	< 4.0	7.4	0.99
49	< 0.19	< 25.4	580	1.5	0.18	70.1	8.9	< 0.086	32.0	< 2.0	8.6	< 0.2
50	< 0.19	< 9.8	192	1.1	0.025	63.7	6.2	< 0.15	34.0	< 2.0	9.4	< 0.2
51	< 0.19	16.5	289	1.1	< 0.05	55.2	52.6	0.024	34.0	< 5.0	7.5	< 0.9
52.1	< 0.19	13.2	187	1.8	< 0.05	70.7	< 3.0	< 0.062	38.0	< 4.0	6.9	< 0.2
52.2	< 0.19	21.1	184	2.2	< 0.05	38.6	2.5	0.018	84.0	2.2	8.6	< 2.0
53	< 0.19	< 25.4	238	0.67	< 0.05	35.5	4.8	< 0.086	13.0	< 3.0	6.9	< 2.0
54	< 0.19	< 11.4	132	0.93	0.3	48.1	19.0	< 0.01	16.0	< 2.0	11.2	< 2.5
55	< 0.19	< 25.4	197	0.6	0.12	61.5	8.0	< 0.086	46.0	< 1.0	8.6	1.31
56	< 0.19	< 25.4	121	0.92	0.085	43.0	12.0	< 0.086	17.0	< 3.0	14.4	< 0.7
57	< 0.19	5.9	231	0.6	0.08	40.2	6.6	< 0.01	28.0	< 4.0	8.1	1.05
58	< 0.19	< 32.2	181	0.66	< 0.02	73.3	10.1	< 0.014	25.0	< 4.0	7.8	< 1.0
59	< 0.19	< 28.4	275	0.61	0.39	41.9	< 1.0	< 0.014	76.0	< 4.0	9.3	0.74
60	< 0.19	22.8	189	1.2	0.21	79.9	1.3	< 0.014	14.0	< 4.0	8.3	< 1.0
61	< 0.19	19	163	1.7	< 0.05	99.3	4.6	< 0.004	< 12.0	< 6.0	10.3	< 0.2
62	< 0.19	18.1	259	1.0	< 0.05	53.8	4.0	< 0.014	25.0	< 1.0	10.1	< 0.2
63	< 0.19	5.13	161	0.54	0.043	36.4	11.8	0.025	18.0	< 0.7	7.1	1.01
64	< 0.19	13.8	357	0.42	< 0.048	59.5	9.2	< 0.02	22.0	< 1.0	7.9	< 0.2
65	< 0.19	22.6	289	1.3	< 0.048	91.0	< 7.0	< 0.004	23.0	< 5.0	9.2	< 0.2
66	< 0.19	11.7	218	0.86	< 0.048	35.8	1.3	0.039	16.0	< 3.0	9.3	1.42
67	< 0.19	< 25.0	91.4	0.57	< 0.03	42.1	10.0	< 0.014	19.0	< 3.0	8.7	< 0.2
68.1	< 0.19	< 12.0	178	1.2	0.031	49.3	25.5	0.0062	15.0	< 5.0	7.5	1.32

COPC = constituent of potential concern
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit

Table A-11: COPC Concentrations in Portland Cement from Portland Cement Association, 1992 (mg/kg)

Sample ID	Antimony	Arsenic	Barium	Beryllium	Cadmium	Chromium	Lead	Mercury	Nickel	Selenium	Silver	Thallium
68.2	< 0.19	< 7.2	164	1.8	< 0.05	59.8	11.2	< 0.0001	17.0	< 0.6	7.3	2.47
70	< 0.19	11.8	266	0.52	< 0.048	85.2	3.2	< 0.014	23.0	< 4.0	8.4	< 0.3
71	< 0.19	17.1	216	< 1.03	0.055	56.4	12.8	< 0.01	< 17.0	1.4	7.3	< 0.2
72	< 0.19	6.9	375	1.7	0.28	54.5	64.3	< 0.02	19.0	< 4.0	7.6	1.13
73	< 0.19	9.9	183	0.59	0.17	56.2	54.7	0.046	19.0	< 2.0	8.0	< 0.2
74	< 0.19	20.9	226	0.62	< 0.048	47.3	< 2.0	< 0.014	23.0	< 4.0	13.0	2.09
75	< 0.19	12.4	198	0.85	0.56	135	5.7	0.021	39.0	< 3.0	8.2	< 0.2
76	< 0.19	43.4	250	3.1	0.59	81.2	11.9	0.014	< 22.0	< 5.0	8.3	2.59
77	< 0.19	11.6	104	0.68	< 0.05	49.7	< 3.0	< 0.02	30.0	< 4.0	11.5	< 1.0
78	< 0.19	< 28.8	300	1.5	< 0.05	58.7	2.3	< 0.014	26.0	< 3.0	8.4	1.34
79	< 0.19	12.4	172	0.87	< 0.04	49.0	13.9	< 0.01	21.0	< 3.0	11.5	< 0.5
80	< 0.19	7.3	229	1.8	1.12	72.9	10.3	< 0.01	21.0	< 4.0	7.0	< 2.0
81	< 0.19	24.5	163	0.92	0.37	55.5	14.4	< 0.01	11.0	< 4.0	7.1	< 2.0
82	< 0.19	9.1	275	1.3	0.04	65.0	6.0	< 0.01	21.0	< 4.0	8.5	0.2
83	< 0.19	12.1	461	0.90	< 0.05	54.5	2.5	< 0.01	48.0	< 2.0	8.0	0.97
84	< 0.19	70.6	197	1.5	< 0.13	167	6.5	0.025	76.0	< 4.0	8.8	< 0.6
93.1	< 0.19	140	111	1.4	0.04	24.6	3.3	0.0002	39.0	< 2.0	19.9	0.78
94	< 0.19	< 9.0	466	1.6	< 0.05	138	< 5.0	0.00005	34.0	< 4.0	9.4	< 0.2
96	< 0.19	< 3.0	168	1.1	< 0.05	184	< 10.0	0.0001	68.0	< 0.9	8.3	< 0.2
97	< 0.19	< 8.0	140	1.4	< 0.048	153	5.1	0.00005	41.0	< 4.0	9.4	< 0.2
98.1	< 0.19	9.0	310	1.1	< 0.03	248	10.8	0.00005	34.0	< 4.0	9.1	< 0.4
98.2	< 0.19	8.2	313	1.4	0.13	245	14.8	0.0002	36.0	0.62	9.4	< 0.2
99	< 0.19	< 11.0	229	1.1	0.47	136	34.3	< 0.00003	34.0	< 4.0	10.6	< 0.2

COPC = constituent of potential concern
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit

A.2.12 Pflughoeft-Hassett et al., 1993

ACAA provided a study by the University of North Dakota Energy and Environmental Research Center titled *Comparative Leaching of Midwestern Coal Fly Ash and Cement* (Pflughoeft-Hassett et al., 1993). This study analyzed four samples of portland cement and fly ash for concentrations of arsenic, barium, boron, cadmium, chromium, cobalt, copper, lead, manganese, mercury, molybdenum, nickel, selenium, silver, vanadium, and zinc. This study prepared and analyzed all samples using particle induced x-ray emission. **Table A-12** provides the raw portland cement data on COPCs available from this study. The CCR Constituent Database includes fly ash data from this report (**Section A.2.1**). When utilizing these data, the current evaluation incorporated non-detect values using half of the reported detection limit based on the recommendations in *Risk Assessment Guidance for Superfund (RAGS) Part A* (US EPA, 1989) and with *EPA Region 3 Guidance on Handling Chemical Concentration Data near the Detection Limit in Risk Assessments* (US EPA, 1991).

Table A-12: COPC Concentrations in Portland Cement from Pflughoeft-Hassett et al., 1993 (mg/kg)

COPC	Sample ID			
	C1	C2	C3	C4
Arsenic	3.6	18.0	8.4	3.7
Barium	27.0	90.0	360	179
Boron	43.0	55.0	42.0	*< 40.0*
Cadmium	*< 1.0*	*< 1.0*	*< 1.0*	*< 1.0*
Chromium	55.0	46.0	40.0	21.0
Cobalt	< 10	10.0	< 10.0	< 10.0
Copper	12.0	30.0	38.0	9.0
Lead	8.2	*< 2.0*	7.1	5.3
Manganese	250	400	230	260
Mercury	0.14	0.22	0.08	0.52
Molybdenum	*< 10.0*	17.0	*< 10.0*	*< 10.0*
Nickel	*< 20.0*	22.0	*< 20.0*	*< 20.0*
Selenium	*< 0.40*	*< 0.40*	*< 0.40*	*< 0.40*
Silver	*< 0.20*	*< 0.20*	*< 0.20*	*< 0.20*
Vanadium	20.0	59.0	43.0	34.0
Zinc	19.0	64.0	21.0	*< 10.0*

COPC = constituent of potential concern
mg/kg = milligrams per kilogram
< = non-detect; value represents lowest reported detection limit

A.2.13 Shock et al., 2009

This study analyzed three samples of both mined gypsum wallboard and FGD gypsum wallboard for mercury concentrations and mercury emanation rates. First, the study measured the initial mercury concentration in the wallboards using CV-AFS. Next, the research team placed the wallboard into an air-tight container and collected the mercury emitted into the container in a three-step process. First, the study pumped ambient air through both an iodated carbon trap and gold-coated sand trap to remove any mercury already present in the ambient air. Next, the research team pumped purified air through the container to entrain any mercury emitted by the wallboard. Finally, they pumped the air through another iodated carbon trap or gold-coated sand trap to capture all of the mercury emitted by the wallboard. The study analyzed all samples by CV-AFS. During analysis, the researchers found that iodated carbon traps had a higher detection limit than the gold-coated traps.

Table A-13 presents the raw mercury data for the gold-coated sand trap samples available from this study. All samples collected with the iodated carbon traps were below the associated detection limit of 11.5 ng/m^2-day. Therefore, these data do not provide useful information and this evaluation did not retain them for further consideration. This evaluation converted concentrations to ng/m^2-hr by making the necessary unit conversions.

Table A-13: Mercury Concentrations and Emanation Rates for Mined Gypsum Wallboard and FGD Gypsum Wallboard from Shock et al., 2009

Type of Sample	Sample ID	Mercury Concentration (mg/kg)	Emanation Rate (ng/m^2-day)	Duplicate Emanation Rate (ng/m^2-day)
Mined Wallboard	NG062206	0.0009 ± 0.0002	0.93	N/A
Mined Wallboard	NG062306	0.0009 ± 0.0002	1.03	N/A
Mined Wallboard	NG062406	0.0009 ± 0.0002	0.73	0.89
FGD Wallboard	SG072206	0.15 ± 0.02	6.75	5.82
FGD Wallboard	SG072306	0.15 ± 0.02	8.19	N/A
FGD Wallboard	SG072406	0.15 ± 0.02	3.35	N/A

FGD = flue gas desulfurization
mg/kg = milligrams per kilogram
ng/m^2-day = nanograms per meter squared - day
N/A = not applicable; a duplicate sample was not collected

A.2.14 US Environmental Protection Agency, 2009

This study analyzed 11 samples of unwashed FGD gypsum and nine samples of washed FGD gypsum for concentrations of mercury provided by 13 separate coal combustion facilities. This study analyzed all samples for mercury concentrations according to EPA Method 7470A and select samples according to EPA Method 7473 to compare and confirm the accuracy of the measurements. **Table A-14** provides raw mercury data available from this study. Because this study analyzed several samples with two different methods, the current evaluation incorporated the maximum reported value.

Table A-14: Mercury Concentrations in FGD Gypsum from US EPA, 2009 (mg/kg)

Site ID	Gypsum Conditions*	Mercury (Method 7470)	Mercury (Method 7473)
Facility U	Unwashed	0.25	0.09
Facility T	Unwashed	0.8	0.51
Facility T	Washed	0.89	0.66
Facility W	Unwashed	0.79	N/A
Facility W	Washed	0.77	0.62
Facility Aa	Unwashed	0.53	0.63
Facility Aa	Washed	0.37	0.49
Facility Da	Washed	0.45	0.43
Facility P	Unwashed	0.01	N/A
Facility N	Unwashed	0.54	N/A
Facility N	Washed	0.05	N/A
Facility S	Unwashed	0.31	0.26
Facility S	Washed	0.3	0.26
Facility O	Unwashed	0.39	N/A
Facility O	Washed	0.04	N/A
Facility R	Unwashed	0.26	0.23
Facility Q	Unwashed	0.51	N/A
Facility X	Unwashed	1.2	2.0
Facility X	Washed	0.82	0.94
Facility Ca	Washed	1.8	3.1

FGD = flue gas desulfurization

mg/kg = milligrams per kilogram

N/A = data was not collected using this method

* Unwashed gypsum is FGD gypsum as generated. Washed gypsum has been treated to remove fines and impurities. FGD gypsum is typically washed prior to the production of wallboard.

A.2.15 Yost et al., 2010

This study analyzed 74 samples of mined gypsum and 13 samples of unwashed FGD gypsum produced in the United States for mercury concentrations. The Georgia-Pacific Company provided the gypsum samples from each of its wallboard manufacturing facilities, 15 of which use mined gypsum and three of which use FGD gypsum. Each sample represents a composite of the gypsum used during a given month. This study analyzed all samples for mercury concentrations according to EPA Method 7471A. **Table A-15** provides the summary statistics on mercury concentrations available from this study. When utilizing these data, the current evaluation incorporated non-detect values using half of the reported detection limit based on the recommendations in *Risk Assessment Guidance for Superfund (RAGS) Part A* (US EPA, 1989) and with *EPA Region 3 Guidance on Handling Chemical Concentration Data near the Detection Limit in Risk Assessments* (US EPA, 1991).

Table A-15: Mercury Concentrations in FGD Gypsum and Mined Gypsum from Yost et al., 2010 (mg/kg)

Types of Sample	Detection Frequency	Minimum	Average	Maximum
Mined Gypsum	46 / 74	*< 0.009*	0.0210	0.256
FGD Gypsum	13 / 13	0.073	0.383	0.539

mg/kg = milligrams per kilogram

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Appendix B:

Identification of Relevant Screening Benchmarks

Table of Contents

B.1 Introduction

This appendix discusses the relevant screening benchmarks identified for COPCs carried forward to Step 4 (Screening Assessment) of the evaluation for fly ash concrete and FGD gypsum wallboard. These screening benchmarks were drawn from established values (e.g., ecological soil screening levels) and/or health-based values calculated for this specific evaluation based on available toxicological and exposure data (i.e., based on a cancer risk of 1×10^{-5} or a hazard quotient of 1.0). For purposes of this evaluation, the most conservative of the benchmarks identified for each exposure pathway was used. It is important to note that the relevant screening benchmarks for other beneficial use evaluations may not necessarily be the same as those discussed in this document. In some cases, other appropriate benchmarks may be available, or have already been defined by state or federal regulatory bodies.

B.2 Human Exposure to Soil and Dust

Health-based numbers (HBNs) were identified as the relevant screening benchmark for this exposure pathway. HBNs are a type of human health screening benchmark calculated based on available exposure and toxicological data for a specified receptor. The HBNs for ingestion of dust mixed into soil were calculated using **Equation B.1** for non-carcinogenic COPCs and **Equation B.2** for carcinogenic COPCs. These equations are equivalent to those presented in US EPA (1991a), adjusting for units and conversions constants, as appropriate.

$$\textbf{Equation (B.1)} \quad HBN = \frac{THQ \cdot RfD \cdot BW \cdot \left(365\,\frac{days}{year}\right) \cdot \left(10^{6}\,\frac{mg}{kg}\right)}{EF \cdot IR}$$

$$\textbf{Equation (B.2)} \quad HBN = \frac{TR \cdot LT \cdot BW \cdot \left(365\,\frac{days}{year}\right) \cdot \left(10^{6}\,\frac{mg}{kg}\right)}{CSF \cdot EF \cdot ED \cdot IR}$$

Where:

THQ – Target Hazard Quotient (unitless)

TR – Target Risk (unitless)

RfD – Reference Dose (mg/kg-day)

CSF – Cancer Slope Factor $(mg/kg\text{-}day)^{-1}$

BW – Body Weight (kg)

LT – Lifetime (yrs)

ED – Exposure Duration (yrs)

EF – Exposure Frequency (days/yr)

IR – Dust Ingestion Rate (mg/day)

HBN – Health-based Number for Soil Ingestion (mg/kg)

B.2.1 Target Hazard Quotient and Target Risk

The target hazard quotient and target risk are unitless numbers that represent the estimated likelihood that a non-carcinogenic or carcinogenic adverse effect will occur. Target hazard quotients, calculated for non-carcinogenic constituents, are the ratio of the constituent concentration to which a receptor may be exposed and the concentration below which no adverse effects are known or anticipated to occur. For this evaluation, the target hazard quotient was set to 1.0 based on the recommendations of US EPA (1989). Target risks are established for carcinogenic constituents. Unlike approaches for assessing some non-carcinogenic constituents, this approach assumes that no level of exposure exists below which cancer cannot occur. Any increase in exposure to a carcinogen translates to some increased probability of developing cancer. The current evaluation considered cancer risks within the 1×10^{-4} and 1×10^{-6} risk range. From this range, the specific target risk of 1×10^{-5} was selected based on the US EPA Office of Resource Conservation and Recovery's presumptive listing benchmark (59 FR 66075). This level is equivalent to one additional incidence of cancer for every 100,000 individuals exposed to a given carcinogen.

B.2.2 Reference Dose and Cancer Slope Factor

Reference dose and cancer slope factor are human-health toxicity values that describe the exposure-response relationship between a constituent and a receptor. Reference doses are estimates of a daily oral exposure (including exposures to individuals in sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime. Cancer slope factors are developed for carcinogens and are upper bounds, approximating a 95 percent confidence limit, of the increased cancer risk from a lifetime exposure to an agent by ingestion.

This evaluation selected these toxicity values from available sources based on the selection hierarchy detailed in the 2003 *Office of Solid Waste and Emergency Response Directive 9285.7-53* (US EPA, 2003). This memorandum encourages the prioritization of toxicity values from sources that are current, that are transparent and publicly available, and that have been peer-reviewed. This evaluation chose values from the Integrated Risk Information System (IRIS), the Provisional Peer Reviewed Toxicity Values for Superfund (PPRTVs), the Agency for Toxic Substances and Disease Registry (ATSDR) and the New Jersey Department of Environmental Protection (NJDEP). **Table B-1** presents toxicity values selected for this evaluation. The toxicity values listed in this table are current as of December 2013.

Table B-1: Human Health Toxicity Values

COPC	CASRN	Toxicity Value	Receptor Endpoint	Source	Last Updated
Cancer Slope Factor (mg/kg-day)$^{-1}$					
Arsenic	7440-38-2	1.5	Cancer	IRIS	Apr. 1998
Chromium (VI)	18540-29-9	0.5	Cancer	NJDEP	July 2009
Noncancer Reference Dose (mg/kg-day)					
Aluminum	7429-90-5	1.0	Neurological	PPRTV	Oct. 2006
Antimony	7440-36-0	0.0004	Hematological	IRIS	Feb. 1991
Arsenic	7440-38-2	0.0003	Dermal	IRIS	Feb. 1993
Barium	7440-39-3	0.2	Renal	IRIS	July 2005
Beryllium	7440-41-7	0.002	Gastrointestinal	IRIS	Apr. 1998
Boron	7440-42-8	0.2	Developmental	IRIS	Aug. 2004
Cadmium	7440-43-9	0.001 (food) 0.0005 (water)	Hepatic	IRIS	Feb. 1994
Chromium (VI)	18540-29-9	0.003	NOAEL	IRIS	Sept. 1998
Cobalt	7440-48-4	0.0003	Thyroid	PPRTV	Aug. 2008
Copper	7440-50-8	0.01	Gastrointestinal	ATSDR	Oct. 2004
Iron	7439-89-6	0.7	Gastrointestinal	PPRTV	Sept. 2006
Lead	7439-92-1	--	--	--	--
Mercury	7487-94-7	0.0003	Immunological	IRIS	May 1995
Molybdenum	7439-98-7	0.005	Metabolic	IRIS	Aug. 1993
Nickel	7440-02-0	0.02	Cardiovascular, Hepatic	IRIS	Dec. 1996
Selenium	7782-49-2	0.005	Dermal, Hematological, Neurological	IRIS	Sept. 1991
Strontium(1)	7440-24-6	0.6	Bone	IRIS	Dec. 1996
Thallium	7440-28-0	0.00001	Dermal	PPRTV	Oct. 2010
Uranium(1)	7440-61-1(2)	0.003	Renal	IRIS	Oct. 1989
Vanadium	1314-62-1	0.009	Hair	IRIS	Dec. 1996
Zinc	7440-66-6	0.3	Hematological	IRIS	Aug. 2005

ATSDR = agency for toxic substances and disease registry
CASRN = chemical abstract service registry number
COPC = constituent of potential concern
IRIS = integrated risk information system
NJDEP = new jersey department of environmental protection
NOAEL = no observable affects evaluation level
PPRTV = provisional peer-reviewed toxicity values
mg/kg-day = milligram per kilogram-day
(1) Values presented are for chemical toxicity only.
(2) Because no CASRN exists for uranium salts, the reported CASRN is for elemental uranium.

B.2.3 Body Weight

Body weight is a measurement of an individual's total mass. This evaluation selected the average age-specific body weight across both genders based on EPA policy (US EPA, 1991b). **Table B-2** presents the age-specific values selected for this evaluation.

Table B-2: Age-Specific Body Weights (kg)

Age	0 to <1	1 to <2	2 to <3	3 to <6	6 to <11	11 to <16	16 to <21	> 21
Weight	9.2(1)	11.4	13.8	18.6	31.8	56.8	71.6	70
Source	US EPA, 2008a Table 8-1							US EPA, 1991b

kg = kilogram
(1) Value represents a time-weighted average of each age cohort reported within the first year.

B.2.4 Lifetime

Lifetime is the anticipated lifespan of an individual. This evaluation used a value of 70 years for all residents based on EPA policy (US EPA, 1991).

B.2.5 Exposure Duration

Exposure duration is the length of time that an individual may be exposed to a COPC. This evaluation uses a value of 30 years for all residents based on EPA policy (US EPA, 1991b). These 30 years were broken down into individual age cohorts based on two potential scenarios. The first scenario assumed that the receptor is exposed for 30 years starting at birth. This scenario calculated the duration for children as the amount of time spent in a given age cohort, resulting in an exposure duration of nine years for adults. The second scenario assumed that all 30 years were spent in the adult cohort. **Table B-3** presents the selected age-specific values selected for this evaluation.

Table B-3: Age-Specific Exposure Durations (years)

Age	0 to <1	1 to <2	2 to <3	3 to <6	6 to <11	11 to <16	16 to <21	> 21
Duration	1	1	1	3	5	5	5	9 or 30
Source	Calculated							US EPA, 1991b

B.2.6 Exposure Frequency

Exposure frequency is the frequency that an individual is exposed to a COPC throughout a given time period. This evaluation selected a value of 350 days/year based on EPA policy (US EPA, 1991b). This value assumes that residents take an average of two weeks of vacation away from their homes each year and applies to all age cohorts.

B.2.7 Soil Ingestion Rate

The soil ingestion rate is the amount of soil incidentally consumed by an individual during a given time period. This evaluation selected a total soil ingestion rate of 200 mg/day for all child cohorts and

100 mg/day for adults based on EPA policy (US EPA, 1991b). These values represent a best estimate of upper-bound values for combined soil and dust ingestion currently available, and are based on the same studies presented in the 1997 *Exposure Factors Handbook* (US EPA, 1997). Sufficient cohort-specific data were not identified in either the 2008 or 2011 Handbooks to update these recommendations (US EPA, 2008a; 2011).

B.2.8 Health-based Numbers for Ingestion of Soil and Dust

HBNs are designed to be protective for humans (including sensitive groups) over a lifetime of incidental exposure to outdoor dust and soil. **Table B-4** presents the screening benchmarks calculated for each COPC carried forward to Step 4 (Screening Assessment) of the evaluation. This evaluation did not calculate dust screening benchmarks for the infant age cohort (0 to < 1 years) because this age range is not anticipated to have frequent contact with soils in the vicinity of a major roadway. In instances where a COPC has the potential to result in both cancer and noncancer effects, the evaluation retained the more conservative of the two resulting screening benchmarks.

Table B-4: Health-based Numbers for Dust Ingestion (mg/kg)

COPC	Benchmark	Type
Aluminum	59,443	Noncancer
Antimony	23.8	Noncancer
Arsenic	3.6	Cancer
Barium	11,889	Noncancer
Beryllium	119	Noncancer
Boron	11,889	Noncancer
Cadmium	59.4	Noncancer
Chromium (VI)	10.8	Cancer
Cobalt	17.8	Noncancer
Copper	594	Noncancer
Iron	41,610	Noncancer
Lead(1)	400	Noncancer
Mercury	17.8	Noncancer
Molybdenum	297	Noncancer
Nickel	1,189	Noncancer
Selenium	35,666	Noncancer
Strontium(2)	297	Noncancer
Thallium	0.60	Noncancer
Uranium(2)	178	Noncancer
Vanadium	535	Noncancer
Zinc	17,833	Noncancer

COPC = constituent of potential concern

mg/kg = milligram per kilogram

(1) Screening benchmark represents current EPA Action Level (US EPA, 1994)

(2) Values presented are for chemical toxicity only.

B.3 Ecological Exposure to Soil and Dust

Ecological Soil Screening Levels (Eco-SSLs) were identifited as the relevant screening benchmark for this exposure pathway. Eco-SSLs are concentrations developed to be protective of ecological receptors that commonly come into contact with dust and soil, or ingest biota that live in the soil. **Table B-5** presents the Eco-SSLs identified for each COPC carried forward to Step 4 (Screening Assessment) of the evaluation. At present, no Eco-SSLs have been developed for boron, iron, mercury, molybdenum, strontium, thallium, or uranium. The values listed in this table are current as of December 2013.

Table B-5: Ecological Screening Benchmarks for Dust Exposure (mg/kg)

COPC	Receptor	Benchmark	Source
Antimony	Mammalian	0.27	US EPA, 2005a
Arsenic	Plants	18.0	US EPA, 2005b
Barium	Biota	330	US EPA, 2005c
Beryllium	Mammalian	21.0	US EPA, 2005d
Cadmium	Mammalian	0.36	US EPA, 2005e
Chromium (VI)	Mammalian	130	US EPA, 2008b
Cobalt	Plants	13.0	US EPA, 2005f
Copper	Avian	28.0	US EPA, 2007a
Lead	Avian	11.0	US EPA, 2005g
Nickel	Plants	38.0	US EPA, 2007b
Selenium	Plants	0.52	US EPA, 2007c
Vanadium	Avian	7.8	US EPA, 2005h
Zinc	Avian	46.0	US EPA, 2007d

COPC = constituent of potential concern
mg/kg = milligram per kilogram

B.4 Human Exposure to Drinking Water

HBNs were identified as the relevant screening benchmark for this exposure pathway. HBNs are a type of human health screening benchmark calculated based on available exposure and toxicological data for a specified receptor. The HBNs for ingestion of drinking water were calculated using **Equation B.3** for non-carcinogenic COPCs and **Equation B.4** for carcinogenic COPCs. These equations are equivalent to equations presented in US EPA (1991a), adjusting for units and conversion constants, as appropriate. Unless otherwise noted, the values used for each variable are the same as those listed in **Section B.2**.

$$\textbf{Equation (B.3)} \quad \frac{THQ \cdot RfD \cdot BW \cdot \left(365\,\frac{days}{year}\right) \cdot \left(10^3\,\frac{\mu g}{mg}\right)}{EF \cdot IR} = HBN$$

$$\textbf{Equation (B.4)} \quad \frac{TR \cdot LT \cdot BW \cdot \left(365\,\frac{days}{year}\right) \cdot \left(10^3\,\frac{\mu g}{mg}\right)}{CSF \cdot EF \cdot ED \cdot IR} = HBN$$

Where:

THQ	–	Target Hazard Quotient (unitless)
TR	–	Target Risk (unitless)
RfD	–	Reference Dose (mg/kg-day)
CSF	–	Cancer Slope Factor $(\text{mg/kg-day})^{-1}$
BW	–	Body Weight (kg)
LT	–	Lifetime (yrs)
ED	–	Exposure Duration (yrs)
EF	–	Exposure Frequency (days/yr)
IR	–	Drinking Water Ingestion Rate (L/day)
HBN	–	Health-based Number (µg/L)

B.4.1 Drinking Water Ingestion Rate

The drinking water ingestion rate is the amount of water that an individual drinks within a given time period. This evaluation selected the drinking water ingestion rate for each age cohort from the 90th percentile values for water ingested from community water supplies, with the assumption that residents who rely on ground water do not have different consumption patterns than those who receive water from public sources. **Table B-7** displays the age-specific values. Because the values in the 2008 *Child-Specific Exposure Factors Handbook* (US EPA, 2008a) are a function of body weight, **Table B-7** presents adult ingestion rate in the same units.

Table B-7: Drinking Water Ingestion Rates (mL/kg-day)

Age	0 to <1	1 to <2	2 to <3	3 to <6	6 to <11	11 to <16	16 to <21	>21
Ingestion Rate	150(1)	56	52	49	35	26	24	28.6(2)
Source	US EPA, 2008a Table 3-19							US EPA, 1991b

mL/kg-day = milliliters per kilogram (body weight) – day
(1) Value represents a time-weighted average of each age cohort reported within the first year.
(2) Value represents the recommended ingestion rate (2 L) divided by the average body weight (70 kg).

B.4.2 Health-based Numbers for Ingestion of Drinking Water

HBNs are designed to be protective for humans (including sensitive groups) over a lifetime of exposure to ground water. **Table B-8** presents the screening benchmarks calculated for each COPC carried forward to Step 4 (Screening Assessment) of the evaluation. In instances where a COPC has the potential to result in cancer and noncancer effects, the evaluation retained the more conservative of the two benchmarks.

Table B-8: Calculated Health-based Numbers for Drinking Water Ingestion (µg/L)

COPC	Benchmark	Type
Antimony	2.8	Noncancer
Boron	1,390	Noncancer
Chromium (VI)	1.4	Cancer
Selenium	34.8	Noncancer

COPC = constituent of potential concern
µg/L = micrograms per liter

B.5 Human Exposure to Fish

HBNs were identified as the relevant screening benchmark for this exposure pathway. HBNs are a type of human health screening benchmark calculated based on available exposure and toxicological data for a specified receptor. The HBNs for ingestion of fish were calculated using **Equation B.5** for non-carcinogenic COPCs and **Equation B.6** for carcinogenic COPCs. These equations combine equations presented in US EPA (1991a) and fish bioconcentration equations presented in Appendix E in US EPA (2010a), adjusting for units and conversions constants, as appropriate. Unless otherwise noted, the values used for each variable are the same as those listed in **Section B.2**.

$$\textbf{Equation (B.5)} \quad HBN = \frac{THQ \cdot RfD \cdot BW \cdot \left(365\,\frac{days}{year}\right) \cdot \left(10^3\,\frac{g}{kg}\right) \cdot \left(10^3\,\frac{\mu g}{mg}\right)}{EF \cdot IR \cdot [(F_{T3} \cdot BCF) + (F_{T4} \cdot BCF)]}$$

$$\textbf{Equation (B.6)} \quad HBN = \frac{\mathrm{TR} \cdot \mathrm{LT} \cdot BW \cdot \left(365\,\frac{\mathrm{days}}{\mathrm{year}}\right) \cdot \left(10^3\,\frac{g}{kg}\right) \cdot \left(10^3\,\frac{\mu g}{mg}\right)}{\mathrm{CSF} \cdot EF \cdot ED \cdot IR \cdot [(F_{T3} \cdot BCF) + (F_{T4} \cdot BCF)]}$$

Where:

THQ – Target Hazard Quotient (unitless)

TR – Target Risk (unitless)

RfD – Reference Dose (mg/kg-day)

CSF – Cancer Slope Factor $(\text{mg/kg-day})^{-1}$

BW – Body Weight (kg)

LT – Lifetime (yrs)

ED – Exposure Duration (yrs)

EF – Exposure Frequency (days/yr)

IR – Fish Ingestion Rate (g/day)

F_{T3} – Fraction of Fish Ingested from Trophic Level 3 (unitless)

F_{T4} – Fraction of Fish Ingested from Trophic Level 4 (unitless)

BCF – Bioconcentration Factor (L/kg)

HBN – Health-based Number for Fish Ingestion (µg/L)

B.5.1 Fish Ingestion Rate

The fish ingestion rate is the amount of fish consumed by an individual over a given time period. This evaluation selected the 90th percentile ingestion rate of 13 g/day from Table 10-64 of the 1997 *Exposure Factors Handbook*. These data originate from a fish consumption study of recreational anglers conducted in Maine, one of four recommended freshwater angler studies in the 1997 *Exposure Factors Handbook*. This evaluation selected the Maine data based on the completeness of the dataset and because it agrees most closely with a separate US Department of Agriculture (USDA) study of national fish consumption (USDA, 1992). The current evaluation identified recreational anglers as most representative of the potentially impacted population. Data regarding fish ingestion rates for the general population presented in Table 10-81 of the 1997 *Exposure Factors Handbook* include all sources of fish, which may originate far from water bodies of interest. Fish ingestion rates for Native American subsistence anglers are currently limited, can vary widely among tribes, and are unlikely to be representative of heavily urban areas with high concrete density. Child-specific fish ingestion rates are currently not available. This evaluation made the conservative assumption that children consume the same amount of fish as adults. For both children and adults, this evaluation assumed that there is no COPC mass lost during preparation or cooking of fish.

B.5.2 Trophic Level Fraction

The trophic level fraction is the relative fraction of fish that a person consumes from each trophic level. The third trophic level (T3) consists of carnivores that eat herbivores or secondary consumers such as invertebrates and plankton (e.g., carp, smelt, perch, catfish, sucker, bullhead, sauger), while the fourth trophic level (T4) consists of carnivores that eat other carnivores (e.g., salmon, trout, walleye, bass). Because most fish that humans eat fall into one of these two trophic levels, this evaluation assumed that the sum of the T3 and T4 fractions equals 100 percent of the fish consumed by an individual. This study selected 0.36 for the T3 trophic level fraction and 0.65 for the T4 trophic level fraction, based on Table 10-66 of the 1997 *Exposure Factors Handbook*.

B.5.3 Bioconcentration Factor

The bioconcentration factor is a measure of the extent to which a constituent concentrates in the tissue of fish relative to the ambient water. This concentration may result from bioaccumulation of the COPC within an individual organism or biomagnification of the COPC up the food chain. This evaluation derived these values from the available scientific literature that measured these factors. **Table B-9** presents the values used in this evaluation, as well as the scientific literature from which they were drawn.

Table B-9: Bioconcentration Factors (L/kg)

COPC	T3 Value	T4 Value	Reference	Notes
Antimony	0	0	Barrows et al. (1980)	Measured T3 value used as surrogate for T4 value.
Boron	--	--	--	No values identified in the literature
Chromium	0.6	0.6	Stephan (1993)	Measured T4 value used as surrogate for T3 value.
Selenium	490	1,700	Lemly (1985)	--

COPC = constituent of potential concern
L/kg = liters per kilogram

B.5.4 Health-based Numbers for Ingestion of Fish

HBNs are designed to be protective for humans (including sensitive groups) over a lifetime of exposure to fish. **Table B-10** presents screening benchmarks calculated for each COPC carried forward to Step 4 (Screening Assessment) of the evaluation. This evaluation did not calculate fish screening benchmarks for the infant age cohort (0 to <1 years) because this age range is not anticipated to ingest appreciable quantities of fish. In instances where a COPC has the potential to result in cancer and noncancer effects, this evaluation retained the more conservative of the two benchmarks for use in the evaluation. Due to lack of BCFs for boron, and zero BCF for antimony, HBNs could not be calculated for these COPCs.

Table B-10: Calculated Health-based Numbers for Fish Ingestion (µg/L)

COPC	Benchmark	Type
Chromium (VI)	240	Cancer
Selenium	3.6	Noncancer

COPC = constituent of potential concern
µg/L = micrograms per liter

B.6 Ecological Exposure to Surface Water

Ambient Water Quality Criteria (AWQC) were identified as the relevant screening benchmarks for this exposure pathway. AWQC are concentrations developed to be protective of ecological receptors that commonly come into contact with surface water or ingest biota that live in the water. **Table B-11** presents the relevant screening benchmarks identified for each COPC carried forward to Step 4 (Screening Assessment) of the evaluation. At present, an AWQC has not been developed for antimony. The values listed in this table are current as of December 2013.

Table B-11: Ecological Surface Water Screening Benchmarks (µg/L)

COPC	Receptor	Benchmark	Last Updated
Boron	Irrigated Crops	750	1986
Chromium (VI)	Aquatic Biota	11.0	1995
Selenium	Aquatic Biota	5.0	1999

Source: http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm#R
COPC = constituent of potential concern
µg/L = micrograms per liter

B.7 Ecological Exposure to Sediment

The National Oceanic and Atmospheric Administration (NOAA) Screening Quick Reference Tables for freshwater sediment threshold effect levels (TELs) were identified as the relevant screening benchmarks for this exposure pathway. TELs are concentrations developed to be protective of ecological receptors that commonly come into contact with sediment. This evaluation divided each sediment benchmark by a sediment-surface water partition coefficient (K_p) to allow direct comparison to aqueous COPC concentrations. The partition coefficient is the ratio of the COPC concentration in the sediment and the COPC concentration dissolved in surface water at equilibrium. This evaluation used partition coefficients from US EPA (2005i). This evaluation chose mean values because of the highly conservative surface water COPC concentrations used in this evaluation. **Table B-12** presents the sediment screening benchmarks for each COPC carried forward to Step 4 (Screening Assessment) of the evaluation. At present, no TELs have been developed for antimony, boron, or selenium. The values listed in this table are current as of December 2013.

Table B-12: Ecological Sediment Screening Benchmarks

Constituent	Critical Receptor	Original Benchmark (mg/kg)	Literature Source	K_p (L/kg)	Adjusted Benchmark (µg/L)
Chromium (VI)	Sediment Biota	37.3	NOAA, 2008	50.1	744

L/kg = liters per kilogram
mg/kg = milligrams per kilogram
µg/L = micrograms per liter
Kp = sediment-surface water partition coefficient

B.8 Human Exposure to Indoor Air

This evaluation selected the mercury reference concentration of 300 ng/m^3 from IRIS for elemental mercury. The reference concentration represents a level below which deleterious health effects are unlikely for receptors (including sensitive subgroups) continually exposed over their lifetime. This evaluation selected these toxicity values from available sources based on the selection hierarchy detailed in the 2003 *Office of Solid Waste and Emergency Response Directive 9285.7-53* (US EPA, 2003). This memorandum encourages the prioritization of toxicity values from sources that are current, that are transparent and publicly available, and that have been peer-reviewed.

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Appendix C:

Ground Water Modeling

Table of Contents

C.1 Introduction

This appendix details the ground water fate and transport modeling conducted as part of the beneficial use evaluation of fly ash concrete. The purpose of this modeling was to conservatively approximate the magnitude of dilution and attenuation that may occur during transport of constituents of potential concern (COPCs) between the point of release and point of exposure. This evaluation used the Industrial Waste Evaluation Model (IWEM), which has undergone independent external peer review and has been validated in the field. The following sections discuss the conceptual model for the evaluation, as well as the conservative data and assumptions used as inputs for IWEM.

This evaluation considered a six-lane concrete highway as the high-end leaching scenario. Roadways may be built on top of base and sub-base materials intended to promote infiltration and reduce ponding. If cracks or joints present in the concrete roadway are large and numerous enough to allow high infiltration rates, little impedes the leachate from reaching underlying native soils. While other concrete structures (e.g., parking lots) may have a larger total area, they are far more likely to be placed directly over less permeable, compacted soils. In these cases, the amount of water that can infiltrate will be limited both by the soil permeability and the crack geometry, greatly reducing the volume of leachate that can reach ground water. Furthermore, this evaluation anticipates that roads are the concrete structures closest in proximity to private ground water wells. Larger concrete structures are more likely to be located in urban and suburban environments, where a larger percentage of the population receives potable water from municipal sources. Other larger concrete structures that have direct contact with surface water, such as bridges and dams, are exposed to high volumes of water, which will dilute long-term releases from these structures to levels below those considered in this document.

C.2 Conceptual Model

This section discusses the conceptual framework for the IWEM modeling. Concrete is generally considered to be an impermeable material. Although the concrete matrix is interspersed with many interconnected pore spaces, they are microscopic in size. Movement of water through these pore spaces occurs on a timescale that is far longer than that required for water to either runoff or evaporate. As a result, this evaluation assumes that little water infiltrates through structurally sound concrete. However, mechanical loading from vehicles, internal stress from freeze-thaw cycles, expansion or subsidence of underlying soils, and other forces may cause cracks to form in the concrete macrostructure over time (Apul et al., 2002). Regardless of the cause, these cracks provide a direct pathway to underlying ground water.

When more precipitation falls on the concrete than can infiltrate through cracks, the evaluation assumes that the excess water runs off overland. When more precipitation infiltrates through the concrete than can be accepted by the underlying soil, the evaluation assumes that excess water flows laterally through the subsurface. In both instances, the excess water will mix with precipitation falling on the downgradient unpaved shoulder. This mixture will infiltrate through the unpaved shoulder and into the ground water table. Once the soil in the unpaved shoulder has also reached capacity, the remaining runoff and subsurface lateral flow is assumed to flow into the nearby drainage ditch and be carried away. **Figure C-1** provides a simplified cross-sectional view of the potential routes through which precipitation that falls on a concrete highway may travel through the environment.

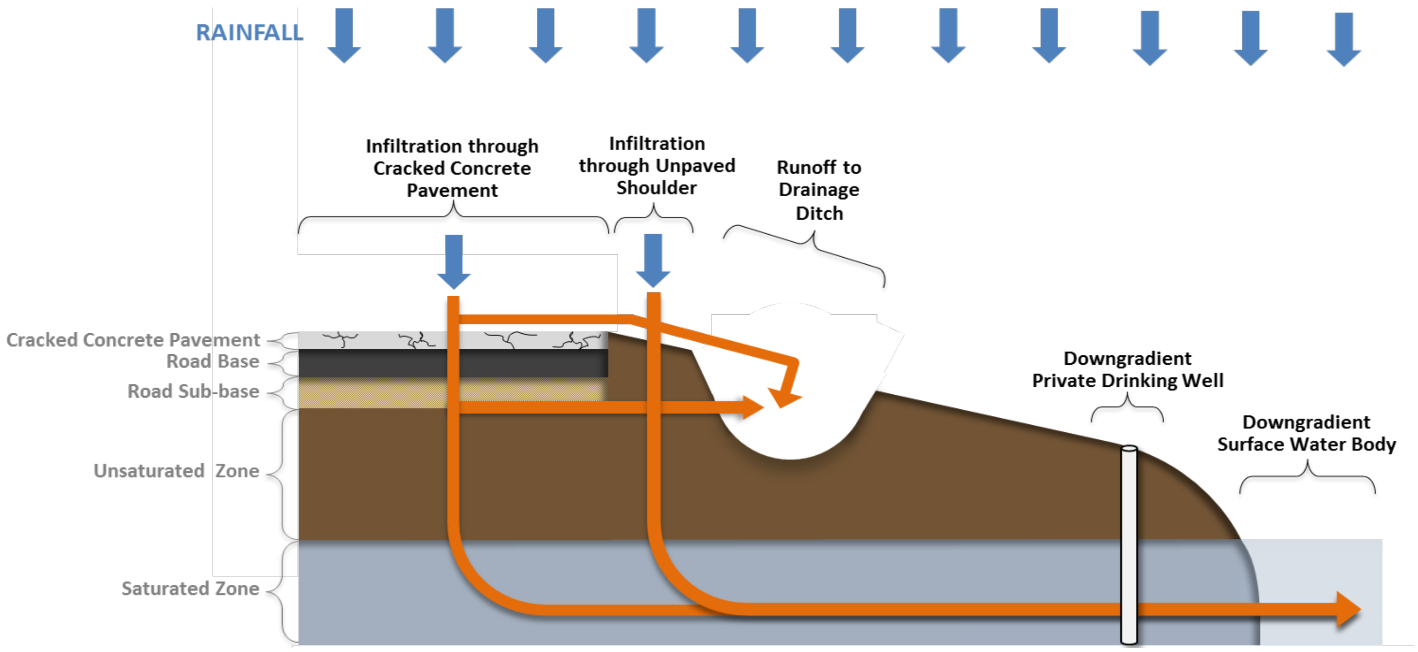

Figure C-1: Cross sectional view of conceptual model.

As the COPCs move through the subsurface environment, they will be diluted in the ground water, dispersed through lateral diffusion, or precipitated out of the aqueous phase through chemical reactions prior to reaching downgradient receptors. These receptors may be residents that derive potable water from untreated ground water or ecological receptors present in a water body fed by ground water. **Figure C-2** provides a simplified aerial view of the releases.

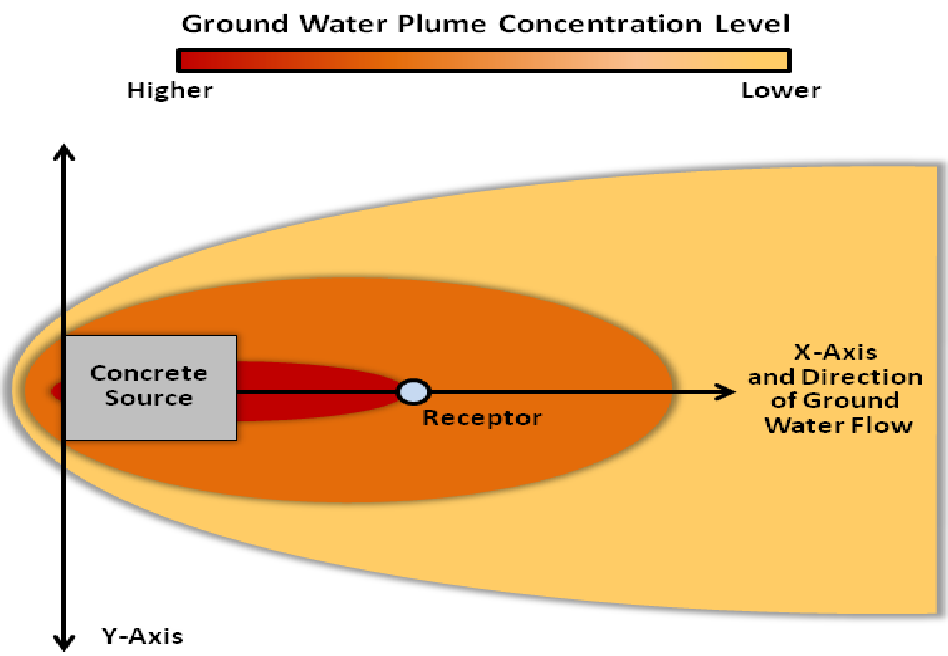

Figure C-2: Aerial view of conceptual model.

C.3 Model Inputs

Model inputs are the information that the user must provide a model in order for it to run. The variables requiring user input were selected based on the results of a sensitivity analyses conducted during the development of IWEM. This sensitivity analysis and the default distributions for the remaining variables are available in IWEM Technical Manual (US EPA, 2010) and are not discussed in this Appendix. The remaining user-defined inputs include: 1) the dimensions of the COPC source, 2) the rate at which water infiltrates through concrete and soil, 3) the concentration of COPCs in leachate, 4) the leachable content of each COPC in concrete, 5) the proximity of receptors to the concrete source, 6) the hydraulic properties of the soil, and 7) the direction of ground water flow relative to the concrete source. IWEM combines these deterministic, user-defined inputs together with default distributions contained within the model to conduct a probabilistic analysis. From this analysis, IWEM generates 90th percentile exposure concentrations. This section discusses each of the user-defined inputs provided to IWEM, as well as the environmental data and assumptions used by this evaluation to generate those inputs.

C.3.1 Source Geometry

Source geometry is the shape and size of the concrete roadway. This evaluation considered a roadway 21.6 m wide, 0.28 m thick, and 5,000 m long. The evaluation selected the width of the highway based on the upper bound of highway lane widths recommended by the American Association of State Highway and Transportation Officials (AASHTO) of 3.6 m together with the assumption that the road is a six-lane highway (AASHTO, 2004). The evaluation selected the thickness of concrete based on the upper bound of road thicknesses recommended in AASHTO (1993). The evaluation did not identify any existing guidance or restrictions on the length of a highway. Instead, values believed to be representative of potential large-scale beneficial use projects were selected. Assuming a 40 percent replacement with fly ash and a density of 2,300 kg/m^3 for finished concrete, the modeled beneficial use project could use up to 4,600 tons of fly ash.

C.3.2 Infiltration Rate

Infiltration rate refers to the amount of water that can pass through a material over a given time period. The lower bound on infiltration through concrete is effectively zero for uncracked concrete. Water will either runoff or evaporate before any appreciable infiltration can occur. The upper bound on infiltration is limited only by the amount of precipitation that falls on the concrete surface. Because the base and sub-base directly underlying roadways are intended to prevent the accumulation of water underneath the roadway, these layers are unlikely to restrict infiltration (Apul et al., 2002).

This evaluation conservatively assumed that the magnitude of cracking across the highway is sufficient to permit unrestricted infiltration through the concrete. The evaluation assumed that the underlying native soil acts as the ultimate limit on infiltration, with a soil infiltration rate selected from the default soil recharge rates contained in IWEM for various climate stations. These default values were previously calculated with the Hydrologic Evaluation of Landfill Performance (HELP) model (US EPA,

1994) using soil characteristic distributions described in Carsel and Parrish (1988). The evaluation selected a conservative infiltration rate for surrounding and underlying soils that corresponds to the 95th percentile national recharge rate for sandy soils. This recharge rate is 0.464 meters per year (m/yr), and corresponds to the weather station in Lake Charles, Louisiana.

C.3.3 COPC Concentrations in Runoff

The evaluation identified mass transfer leachate data from Garrabrants et al. (2013) as the most appropriate source of data available. Mass transfer leaching tests [e.g., EPA Leaching Evaluation Assessment Framework (LEAF) Method 1315] provide information on the cumulative release of constituents from intact concrete, which had been allowed to cure for 3 months, as a function of time. **Table C-1** presents the leachate data for fly ash concrete used in this evaluation. Because the vast majority of precipitation events last less than 2 days, this evaluation retained only data measured for time intervals of up to 2 days. Although selenium was not detected in any of the 3 month samples, it was retained for consideration in Step 4 (Screening Assessment) because the potential for higher leaching from fly ash concrete was identified from a few concrete samples that had been allowed to cure for only 28 days. When utilizing these non-detect data, the current evaluation used half of the reported detection limit. A more detailed discussion of the complete data set is available in **Appendix A**.

Table C-1: Cumulative Releases per Unit Surface Area of Fly Ash Concrete (mg/m^2)

COPC	Maximum Concentration		
	0.08 Day	1 Day	2 Day
Antimony	*< 0.008*	0.027	0.045
Boron	*< 0.10*	*< 0.20*	0.33
Chromium	0.07	0.20	0.30
Selenium	*< 0.052*	*< 0.10*	*< 0.16*

COPC = constituent of potential concern
mg/m^2 = milligrams per square meter
Source: Garrabrants et al. (2013)

Table C-1 reports data in units of milligrams per square meter (mg/m^2) of exposed concrete surface area, which were converted into units of milligrams per liter (mg/L) prior to use in IWEM. The evaluation used **Equation C-1** to make this conversion. This equation was derived by the authors of Kosson et al. (2013) and Garrabrants et al. (2013) (Kosson and Garrabrants, 2012). First, concentrations measured at the initial 0.08 day time interval (C_0) were subtracted from concentrations measured at the 1- and 2-day time intervals (C_1 and C_2) because C_0 frequently reflects sample preparation (e.g., cutting and surface effects) and is not representative of long-term dissolved leachate concentrations (US EPA, 2012). To account for the different volumes of water into which this mass of COPCs are released, this evaluation divided the adjusted C_1 and C_2 by the average amount of water that falls on the concrete during 1 and 2 day precipitation events (D and $2D$), respectively. This assumes that the rate of COPC release from the concrete is constant regardless of the amount of water present. Finally, this evaluation weighted the concentrations during the 1 and 2 day precipitation events by frequency of occurrence during the calendar year.

$$\textbf{Equation (C.1)}\quad C_{rd} = \left[\frac{\left(\frac{C_1 - C_0}{P_{avg}}\right) N_1 + \left(\frac{C_2 - C_0}{2P_{avg}}\right) N_2}{N_1 + N_2}\right]\left(\frac{A_C}{A_W}\right)\frac{\left(1{,}000\,\frac{\mu g}{mg}\right)}{\left(1{,}000\,\frac{L}{m^3}\right)}$$

Where:

C_0 – COPC Concentration at the 0.08 Day Time Interval (mg/m^2)

C_1 – COPC Concentration at the 1-Day Time Interval (mg/m^2)

C_2 – COPC Concentration at the 2-Day Time Interval (mg/m^2)

A_C – Total Surface Area of Concrete in Contact with Water (m^2)

A_W – Cross-Sectional Area of Water in Contact with Concrete (m^2)

N_1 – Annual Number of Runoff Events Less than a Day (Unitless)

N_2 – Annual Number of Runoff Events Greater than a Day (Unitless)

P_{avg} – Average Precipitation per Day of Runoff (m)

C_{rd} – Average COPC Concentration in Water Infiltrating through Roadway (µg/L)

- **Table C-1** presents the COPC concentrations at each time interval (C_0, C_1, and C_2). This evaluation incorporated non-detect values into the calculations using half of the reported detection limit based on the recommendations in *Risk Assessment Guidance for Superfund (RAGS) Part A* (US EPA, 1989) and with *EPA Region 3 Guidance on Handling Chemical Concentration Data near the Detection Limit in Risk Assessments* (US EPA, 1991).

- For precipitation falling on a flat concrete surface, the cross-sectional area (A_W) of water in contact with the concrete is the same as the total surface area of the concrete in contact with the water (A_C). As a result, for water passing over the concrete surface, these two variables are equal. For water infiltrating through cracks in the concrete, A_C may be higher than A_W. However, based on the high infiltration rates through the concrete assumed in this evaluation, the contact time between the crack and the infiltrating water is negligible. Therefore, contributions from this additional crack surface area are not considered. Although smaller cracks may impede water flow and allow higher concentrations to accumulate in the water that passes through the concrete, the much larger volume of water that can pass through the larger and more numerous cracks modeled in this evaluation, together with the conservative COPC concentrations calculated, will result in higher mass flux into the subsurface. Even if a smaller crack size and configuration exists that could result in higher mass fluxes than those considered in this evaluation, these cracks will propagate and expand, becoming larger with time. Thus, small cracks are likely to be less representative of a long term, high-end leaching scenario.

- This evaluation calculated the average number of rainfall events less than and greater than a day (N_1 and N_2) using historical precipitation data for Lake Charles, Louisiana. This location was chosen to correspond to the soil infiltration rates selected. These data were drawn from the HELP model defaults for calendar years 1974 through 1978. This evaluation used five years of data to avoid biasing the calculations toward any extreme events that may have occurred in a given year. For each year of data, this evaluation calculated N_1 and N_2 by summing the number of runoff events lasting less than and greater than a day, respectively. Precipitation events resulting in a total water depth less than 3 mm were assumed not to result in runoff and were subtracted from the final tally (Wanielista and Yousef, 1992). **Table C-2** presents the average values calculated.

Table C-2: 5-Year Average Precipitation Data

Number of Precipitation Events	Number of Days Resulting in Runoff	Number of Runoff Events Less than One Day	Number of Runoff Events Greater than One Day
106	64	31	33

- This evaluation calculated the average precipitation depth per day of runoff (P_{avg}) using the same historical precipitation data used to calculate N_1 and N_2. For each year of data, the evaluation calculated the total amount of runoff by summing the precipitation on days with runoff. This calculation did not consider losses of water volume to evapotranspiration. This evaluation divided the total amount of precipitation resulting in runoff by the total number of days that runoff occurs to obtain P_{avg}. **Table C-3** presents the average values calculated.

Table C-3: 5-Year Average Precipitation per Runoff Event

Total Precipitation (m)	Precipitation Resulting in Runoff (m)	Precipitation Per Runoff Event (m/day)
1.69	1.28	0.02

m = meters

Equation C-1 does not place an upper limit on COPC concentrations (C_{rd}). However, C_{rd} is limited by the prevailing chemistry of the surrounding environment. When C_{rd} reaches this limit, the runoff and concrete are in equilibrium. To determine whether the calculated C_{rd} is higher than the range of potential equilibrium concentrations, C_{rd} was compared to the LEAF Method 1313 data presented in Kosson et al. (2013). Method 1313 was used to determine the liquid-solid partitioning between water and a solid material at equilibrium over a broad range of pH values. The theoretical range of concrete porewater pH values falls between a pH of 7 and 13. An initial pH of around 12.5 is common for newly poured concretes based on the dissolution chemistry of portlandite, a major mineral component of cement composed primarily of calcium hydroxide [$Ca(OH)_2$]. However, over time, concrete will react with atmospheric carbon dioxide [CO_2] through a process known as carbonation. Carbonation gradually converts the calcium hydroxide present to calcium carbonate. Complete carbonation of the concrete matrix coupled with leaching of alkali constituents may result in a pH around 7, based on the dissolution chemistry of the resulting calcium carbonate (Garrabrants et al., 2004). Because the pH of concrete can change with time, randomly selecting a single value probabilistically may underestimate the leaching potential of fly ash concrete. Therefore, this evaluation selected the highest leachate concentration over the theoretical pH range of 7 to 13 for each COPC. **Table C-4** presents the COPC concentrations used to model leachate passing directly through the concrete. All calculated concentrations were at least an order of magnitude below their respective equilibrium concentrations. Therefore, the current evaluation did not need to adjust the calculated concentrations.

Table C-4: Calculated Fly Ash Concrete Leachate Concentrations (µg/L)

COPC	Maximum Calculated Leachate Concentration	Maximum Equilibrium Concentration
Antimony	1.1	20.0
Boron	4.9	3,200
Chromium	6.2	780
Selenium	1.3	48.0

COPC = constituent of potential concern
µg/L = micrograms per liter

The values in **Table C-5** represent COPC concentrations in water as it leaves the concrete. However, this water may run off from the concrete source before infiltrating into the ground water table. This water would be diluted by precipitation that falls over the uncovered soil. Because IWEM Version 2.0 is only designed to consider direct vertical infiltration, this evaluation used **Equation C-2** to account for any dilution that may occur prior to infiltration. This equation was derived from a simple mass balance of the amount of water exiting the concrete and falling directly on the downgradient soil. This evaluation applied the calculated concentrations to the water infiltrating through the road shoulder.

Equation (C·2) $$C_{Sh} = C_{rd}\left(\frac{A_C \cdot [R - I]}{A_C \cdot [R - I] + A_S \cdot P}\right)$$

<u>Where</u>:

C_{rd} – Average COPC Concentration in Water Infiltrating through Roadway (µg/L)

A_C – Surface Area of Concrete (m^2)

A_S – Surface Area of Unpaved Shoulder (m^2)

P – Annual Precipitation (m/yr)

R – Annual Precipitation Resulting in Runoff (m/yr)

I – Infiltration Rate of Soil (m/yr)

C_{sh} – Average COPC Concentration in Water Infiltrating through Shoulder (µg/L)

- The current evaluation obtained the average COPC concentrations in water infiltrating through concrete (C_{rd}) from **Table C-4**.
- This evaluation assumed the length of the concrete roadway and the unpaved shoulder to be the same, and reduced the surface areas (A_C and A_S) to corresponding widths. The width of the roadway was selected as 21.6 m based on the rationale presented in **Section C.1**. The width of the unpaved shoulder was selected as 2.4 m based on the range of typical values listed in AASHTO (2004) for highly traveled roadways.
- The evaluation obtained the annual precipitation (P) and the annual precipitation resulting in runoff (R) from **Table C-3**.
- This evaluation selected the infiltration rate of soil (I) based on the discussion in **Section C.3.2**.

Table C-5 presents the calculated COPC concentrations in water infiltrating through the downgradient shoulder.

Table C-5: Leachate Concentrations for Roadway Shoulder (µg/L)

COPC	Maximum Calculated Runoff Concentration
Antimony	1.0
Boron	4.3
Chromium	5.5
Selenium	1.1

COPC = constituent of potential concern
µg/L = micrograms per liter

C.3.4 Leachable Content

Leachable content is the amount of a given COPC present in the concrete matrix that is available to be released. Once the leachable content of the concrete has been completely depleted, leachate concentrations will become zero. Kosson et al. (2013) measured the leachable content for each concrete sample. This evaluation selected the leachable contents associated with the highest leachate samples measured in Kosson et al. (2013) for use in this evaluation. **Table C-6** presents the selected leachable content for each COPC.

Table C-6: Fly Ash Concrete Leachable Contents (mg/kg)

COPC	Maximum Concentration
Antimony	0.24
Boron	10.0
Chromium	7.4
Selenium	0.78

COPC = constituent of potential concern
mg/kg = milligrams per kilogram

Of the finite mass of COPCs leached from the concrete each year, some fraction will infiltrate beneath the concrete, some fraction will infiltrate beneath the unpaved shoulder, and some fraction will enter the adjacent drainage ditch and either evaporate or be transported away. IWEM Version 2.0 is only designed to consider vertical leaching and cannot account for mass lost from lateral transport. Therefore, the fractions of the leachable content that contribute to infiltration through the roadway and the shoulder must be accounted for through manual calculations and applied to the modeled roadway and shoulder. Assuming that the COPC concentrations dissolved in water leaving the concrete are uniform, the fraction of the mass transported beneath the roadway and the adjacent shoulder each year will equal the fraction of water that infiltrates through each. **Equation C-3** and **Equation C-4** represent a mass balance of the water from concrete that infiltrates beneath the roadway and the adjacent shoulder, respectively. Each year, this evaluation assumed that the same fraction of mass is lost to both the roadway and shoulder until the total leachable content of the concrete is depleted.

$$\textbf{Equation } (\mathbf{C \cdot 3}) \qquad M_{Con} = M_l \left(\frac{I}{R}\right)$$

$$\textbf{Equation } (\mathbf{C \cdot 4}) \qquad M_{Sh} = M_l \left(1 - \frac{I}{R}\right)\left[\frac{(I \cdot A_S)}{(R - I) \cdot A_C + (P \cdot A_S)}\right]\left(\frac{A_C}{A_S}\right)\left(\frac{\rho_C}{\rho_S}\right)$$

Where:

M_l – Leachable Mass of Fly Ash Concrete (mg/kg)
I – Infiltration Rate of Soil (m/yr)
R – Annual Precipitation Resulting in Runoff (m/yr)
P – Annual Precipitation (m/yr)
A_C – Area of Concrete Source (m^2)
A_S – Area of Unpaved Shoulder (m^2)
ρ_C – Density of Concrete (kg/m^3)
ρ_S – Density of Soil (kg/m^3)
M_{Con} – Effective Leachable Mass through Concrete Roadway (mg/kg)
M_{Sh} – Effective Leachable Mass through Unpaved Shoulder (mg/kg)

- This evaluation used the leachable content of fly ash concrete (C_l) listed in **Table C-6**.
- This evaluation selected the infiltration rate of soil (I) based on the discussion in **Section C.3.2**.
- This evaluation used the annual precipitation (P) and the annual precipitation resulting in runoff (R) from **Table C-3**.
- The length of the concrete roadway and the unpaved shoulder are assumed to be the same. Therefore, the surface areas (A_C and A_S) are reduced to corresponding widths. The width of the roadway was selected as 21.6 m based on the rationale presented in **Section C.1**. The width of the unpaved shoulder was selected as 2.4 m based on the range of typical values listed in AASHTO (2004) for highly traveled roadways.
- The density of concrete and soil were assumed to be 2,300 kg/m^3 and 1,600 kg/m^3, respectively. Values for concrete were drawn from PCA (No Date). Values for soil were drawn from US EPA (2010).

Table C-7 presents the effective leachable contents for the concrete roadway and unpaved shoulder. This evaluation assigned the concentrations listed in this table to the roadway and the shoulder in the IWEM model.

Table C-7: Modeled Leachable Contents for Concrete Roadway and Unpaved Shoulder (mg/kg)

COPC	Leachable Content Available for Road	Leachable Content Available for Shoulder
Antimony	0.09	0.10
Boron	3.6	4.1
Chromium	2.7	3.0
Selenium	0.28	0.32

COPC = constituent of potential concern
mg/kg = milligrams per kilogram

C.3.5 Soil Type

Soil type refers to the composition of the soils through which precipitation water migrates. IWEM requires the user to specify the type of subsurface materials for both the unsaturated zone below the source and the saturated zone below the water table. This evaluation selected both soil types as "unknown." For the unsaturated zone, this results in a probabilistic sampling of the different soil types associated with the selected geographic location. For the saturated zone, this selection provides values representative of the average aquifer characteristics across the United States:

- Hydraulic Conductivity: 1,890 m/yr
- Regional Hydraulic Gradient: 0.0057 m/m

C.3.6 Distance to Receptors

The distance to receptors is the shortest straight line distance between the downgradient edge of the concrete source and the modeled receptors. This evaluation assumed the distance to receptors to be limited by the right-of-way surrounding the roadways. Right-of-way is the distance from fence-line to fence-line that is required for highways and accompanying infrastructure. State and local government agencies place restrictions on which activities and structures are appropriate within the right-of way. A review of existing regulations indicates that the right-of-way for interstate highways should be between 150 and 300 ft (45.7 and 91.5 m) (US DOT, No Date). A 300 ft right-of-way is likely to be more representative of rural areas where more vacant land is available for highway construction. In addition, many states and counties have established additional set back distances from highways and other major roads. For example, the New Hampshire Department of Transportation requires private wells to be located at least 50 ft (15.2 m) from state highway right-of-ways (NHDES, 2011). Waupaca County, Wisconsin established a setback distance from state and federal highways of the greater of 110 ft from the centerline of the highway or 50 ft from the right-of-way (Waupaca County Planning and Zoning Department, No Date). These distances are believed to be representative of typical setback distances from major roadways.

For the six lane highway considered in this evaluation, the distance from the centerline of the roadway is 35.5 ft (10.8 m). The combination of a 150 ft right-of-way with an additional 50 ft buffer results in greater distance than the alternative 94.5 ft distance from the centerline of the roadway.

Therefore, this evaluation assumed that private ground water wells were no closer than 200 ft (approximately 60 m) from the edge of the roadway.

C.3.7 Ground Water Flow Direction

The ground water flow direction is the predominant direction of flow across a given area. IWEM requires this input be provided as an angle relative to the downgradient edge of the source. This evaluation selected an angle of 90 degrees. Ground water flowing perpendicular to the concrete source ensures the shortest transport distance between the source and the downgradient receptor.

C.4 Model Results

This section presents the results of the ground water modeling conducted using the inputs discussed throughout this appendix. The results presented were used in Step 4 (Screening Analysis) of the current beneficial use evaluation to identify any COPCs requiring further evaluation in Step 5 (Risk Analysis). For each geographic location, this evaluation modeled all COPCs first at 60 m, and then at subsequent 10 m intervals until ground water concentrations either plateaued or decreased to ensure that the ground water plume was adequately characterized. **Table C-8** presents the results of the modeling using the fly ash concrete data drawn from Garrabrants et al. (2013) and Kosson et al. (2013). Because antimony, boron, and selenium screened out based on a direct comparison to leachate, they are not included in these results.

Table C-8: Modeled Well Concentration (µg/L)

COPC	Concentration at 60m	Concentration at 70m
Chromium	1.1	1.0

COPC = constituent of potential concern
µg/L = micrograms per liter

C.5 References

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