Environment

Prepared for:
American Coal Ash Association
Farmington Hills, MI

Prepared by:
AECOM
Chelmsford, MA
60267598
June 2012

Coal Ash Material Safety

A Health Risk-Based Evaluation of USGS Coal Ash Data from Five US Power Plants

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List of Acronyms

ACAA	American Coal Ash Association
ACI	American Concrete Institute
ACS	American Cancer Society
AECOM	AECOM Technical Services
ATSDR	Agency for Toxic Substances Disease Registry
BMD	Benchmark Dose
BMDL	Benchmark Dose Low
CADD	Chronic Average Daily Dose
CalEPA	California Environmental Protection Agency
CARRC	Coal Ash Resources Research Consortium
CCP	Coal Combustion Product
ELCR	Excess Lifetime Cancer Risk
ENGO	Environmental Nongovernmental Organization
EPC	Exposure Point Concentration
EPRI	Electric Power Research Institute
FGD	Flue Gas Desulfurization
FOD	Frequency of Detection
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HQ	Hazard Quotient
ICPAES	Inductively Coupled Plasma Atomic Emission Spectroscopy
ICPMS	Inductively Coupled Plasma Mass Spectroscopy
IRIS	Integrated Risk Information System
IUR	Inhalation Unit Risk
LADD	Lifetime Average Daily Dose
LOAEL	Lowest Observed Adverse Effect Level
MF	Modifying Factor
mg/kg	milligrams of constituent per kilogram of soil
mg/kg-day	milligrams of constituent per kilogram of body weight per day
mg/m^3	milligrams of constituent per cubic meter of air
MRL	Minimal Risk Level
NCEA	National Center for Environmental Assessment
NJDEP	New Jersey Department of Environmental Protection
NOAEL	No Observed Adverse Effect Level
NTP	National Toxicology Program
OSM	Office of Surface Mines
POD	Point of Departure
ppm	parts per million
PPRTV	Provisional Peer-Reviewed Toxicity Value

RCRA	Resource Conservation and Recovery Act
RfC	Inhalation Reference Concentration
RfD	Oral Reference Dose
RME	Reasonable Maximum Exposure
RSL	Regional Screening Level
SAB	Science Advisory Board
SFO	Oral Cancer Slope Factor
UCL	Upper Confidence Limit
UF	Uncertainty Factor
ug	Microgram
ug/L	Microgram per liter
ug/m^3	Microgram per cubic meter of air
US EIA	US Energy Information Administration
USEPA	US Environmental Protection Agency
USGS	US Geological Survey
WHO	World Health Organization

Standard Chemical Symbols

Al	Aluminum
As	Arsenic
Ba	Barium
Be	Beryllium
Bi	Bismuth
Cd	Cadmium
Ca	Calcium
Cl	Chlorine
Co	Cobalt
Cr	Chromium
Cr-3	Trivalent Chromium
Cr-6	Hexavalent Chromium
Cs	Cesium
Cu	Copper
Fe	Iron
Ga	Gallium
Ge	Germanium
Hg	Mercury
K	Potassium
Li	Lithium
Mn	Manganese
Mg	Magnesium
Mo	Molybdenum
Na	Sodium
Nb	Niobium
Ni	Nickel
O	Oxygen
Pb	Lead
S	Sulfur
Sb	Antimony
Sc	Scandium
Se	Selenium
Si	Silicon

Sr	Strontium
Tl	Thallium
Th	Thorium
Ti	Titanium
U	Uranium
V	Vanadium
Y	Yittrium
Zn	Zinc

Executive Summary

ES.1 Summary

The US Geological Survey (USGS)[1] recently published a report that provides data for concentrations of metals and inorganics in coal ash from five power plants across the United States. The objective of this study, undertaken by the American Coal Ash Association (ACAA), was to conduct a human health risk-based evaluation of the USGS coal ash data, using risk-based screening levels developed by the US Environmental Protection Agency (USEPA)[2] that are protective of a child's direct exposure to residential soils (including ingestion, dermal contact and inhalation routes of exposure). These screening levels are considered by the Agency to be protective for daily exposure by humans (including sensitive groups) over a lifetime. Constituent concentrations in coal ash were also compared to background concentrations in soils in the US. The results indicate that with few exceptions constituent concentrations in coal ash are below screening levels for residential soils, and are similar in concentration to background US soils. Thus, coal ash does not qualify as a hazardous substance based on its composition, and it also should not be classified as hazardous on a human health risk basis. Because exposure to constituents in coal ash used in beneficial applications, such as concrete, road base, or structural fill would be much lower than assumed for a residential scenario, these uses should also not pose a direct contact risk to human health.

ES.2 Methods

Coal ash data were downloaded from the USGS report website[1]. Data for eight coal ashes from five different power plants in five states were evaluated as shown in the table below.

Concentration data are available for 20 trace elements – these are called trace elements because they generally comprise less than 1% of the total constituents in either soil or coal ash. Summary statistics were calculated to provide the 10^{th} to 90^{th} percentile values for each constituent for graphical comparisons to the USEPA residential soil screening levels. To account for potential cumulative effects, USEPA methods were used to calculate exposure point concentrations for each dataset for use in conducting cumulative risk screens.

This evaluation takes a worst-case approach by assuming that exposure to CCPs put into beneficial use could be at the same level and intensity as that of a resident child and adult's exposure to soils in a backyard setting. USEPA Regional Screening Levels (RSLs)[2] were used to compare to the coal ash data. These are risk-based screening levels developed by the Agency to be protective of a child's direct exposure to residential soils (including ingestion, dermal contact and inhalation routes of exposure). These screening levels are considered by the Agency to be protective for daily exposure by humans (including sensitive groups) over a lifetime, and include consideration of both potential cancer and noncancer effects.

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[1] USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

[2] USEPA. 2012. Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012.

[2] USEPA. 2012. Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012.
Available at: http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm

State	Coal Source	Coal Ash	# Samples
Alaska	Nenana Coal Province	Fly/Bottom Ash	19
Indiana	Illinois	Fly Ash	13
New Mexico	San Juan	Fly Ash Product Bottom Ash	16 18
Ohio	Appalachian	Fly Ash Bottom Ash	13 15
Wyoming	Powder River	Fly Ash Bottom Ash	15 15

ES.3 Results

The results are shown graphically in Figure ES-1. Of the 20 trace elements evaluated, 15 are present in all ashes included in this evaluation at concentrations less than the USEPA screening levels for residential soils. These are: antimony, barium, beryllium, cadmium, copper, lead, lithium, manganese, mercury, molybdenum, nickel, selenium, strontium, uranium, and zinc.

Arsenic is the only constituent classified by USEPA as a carcinogen for the oral route of exposure. All risks for constituents that are potential carcinogens by the inhalation route of exposure (beryllium, cadmium, hexavalent chromium, cobalt and nickel) are within or well below USEPA's target risk range of 1 in ten thousand to 1 in one million. Potential risks for the upper bound concentration of arsenic in the Ohio power plant fly ash are slightly above the USEPA target risk range; potential risks for arsenic for all other coal ashes are within the USEPA target risk range. Again, these risk estimates assume daily residential exposure to these coal ashes. To provide context, the background cancer rate in the US is 1 in two for men, and 1 in three for women[3].

This conservative screening has also identified noncancer risks above USEPA's target of 1 for arsenic in the Ohio power plant fly ash, and lithium in the Indiana fly ash. Chromium in this analysis was identified slightly above USEPA's target of 1 for three of the coal ashes. In this risk screening all chromium was assumed to be in the hexavalent form (the trivalent form is essentially nontoxic) and dose-response values currently on USEPAs database were used for this analysis. Data for the Alaska power plant coal ash indicate that hexavalent chromium makes up only 0.25% of the total chromium, and literature data indicate that hexavalent chromium can comprise up to 5% of total chromium. Thus, the assumption that all chromium is in the hexavalent form for all coal ashes in this analysis is conservative (i.e., is likely to overestimate risks). Cobalt and thallium results were each above the USEPA target of 1 for five of the scenarios evaluated. However, there are great uncertainties in the derivations of the toxicity values used to evaluate these two constituents. The toxicity value for cobalt is a provisional value from USEPA. Other regulatory agencies have declined to develop a long-term toxicity value for cobalt citing a "lack of suitable data." The estimated dietary intake in the U.S. is higher than the toxicity value. Similarly, USEPA evaluated the data for thallium and concluded that there were not suitable data to develop a toxicity value. However, USEPA

[3] American Cancer Society. 2012. Cancer Facts & Figures 2012. Available at: http://www.cancer.org/Research/CancerFactsFigures/CancerFactsFigures/cancer-facts-figures-2012

provided "…an appendix with a "screening subchronic and chronic p-RfD" is provided, recognizing the quality decrements, which may be of value under certain circumstances" and noted in that appendix that "[F]or the reasons noted in the main document [because of limitations in the database of toxicological information], it is inappropriate to derive a provisional subchronic or chronic p-RfD for thallium." Thus the results for thallium and cobalt must be viewed recognizing these great uncertainties.

Again, these risk results represent a residential scenario where coal ash is available as soil for exposure by children and adults on a daily basis, underscoring the very conservative and health-protective nature of this evaluation. In the majority of beneficial use settings, exposure would be far less than that assumed for the residential scenario used here. Therefore, this assumption provides for a conservative evaluation of potential risk for CCP beneficial uses.

ES.4 Impact on Regulation and Legislation

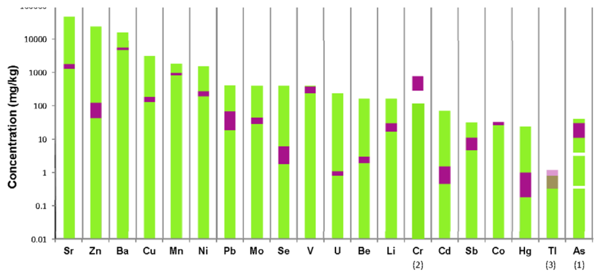
USEPA is in the process of developing regulations for the disposal of coal ash. As this process has been delayed, Congress has taken action. A bill to provide for the regulation of coal ash disposal, The Coal Residuals Reuse and Management Act, H.R. 2273, passed the House of Representatives by a bi-partisan vote of 267 to 144. That bill was introduced into the Senate as S. 1751. Because of the importance of coal ash as a construction material in the transportation industry[4], H.R. 2273 was offered as an amendment to the House version of the Transportation Bill, H.R. 4348. Each of these pieces of legislation would amend Subtitle D of the Resource Conservation and Recovery Act (RCRA) to set the bar for the regulation of coal ash by establishing a robust set of minimum federal requirements for the management and disposal of coal ash that will ensure safety and the protection of human health and the environment. The results of this study support a Subtitle D, non-hazardous, regulation for the disposal of coal ash. The swift development of such regulation, either by legislative or administrative means, would provide the coal ash beneficial use industry the certainty it needs to continue its successful recycling activities.

[4] ARTBA. 2011. The Economic Impacts of Prohibiting Coal Fly Ash Use in Transportation Infrastructure Construction. Transportation Development Foundation. The American Road & Transportation Builders Association. Available at: http://www.artba.org/mediafiles/study2011flyash.pdf

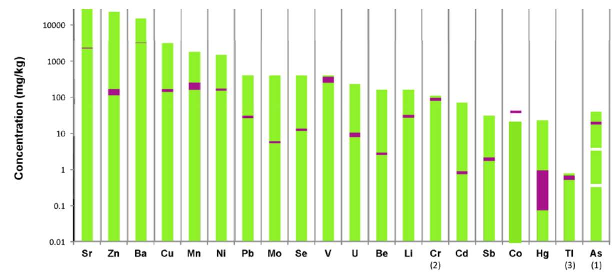
AECOM

Comparison of 10th to 90th Percentile USGS Database Constituent Concentrations in Coal Ash to USEPA Screening Levels for Residential Soils

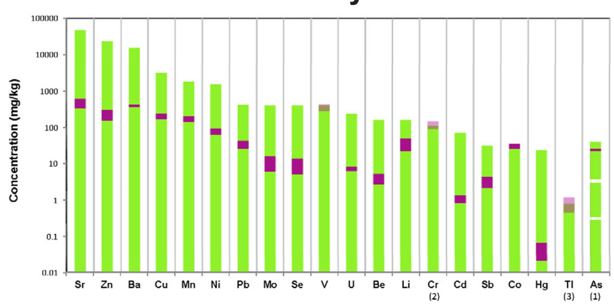
Alaska Fly/Bottom Ash



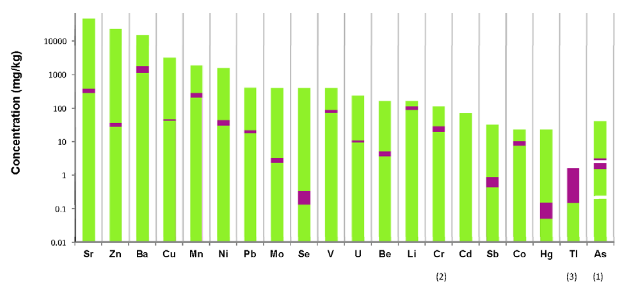
Wyoming Fly Ash



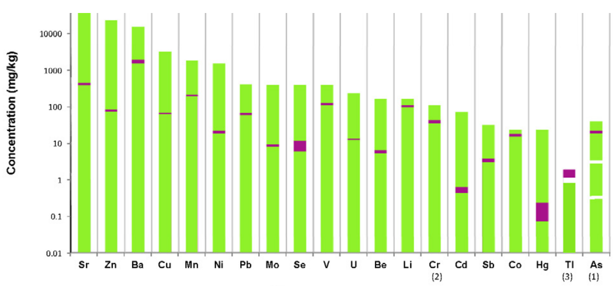
Indiana Fly Ash



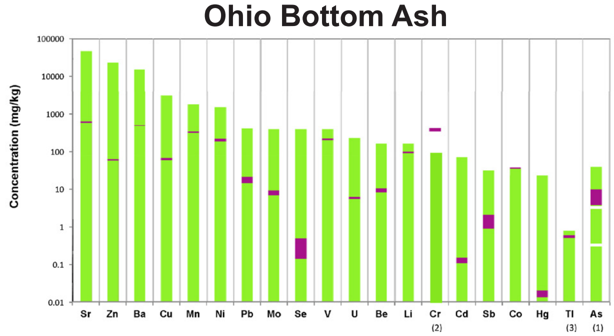
New Mexico Bottom Ash



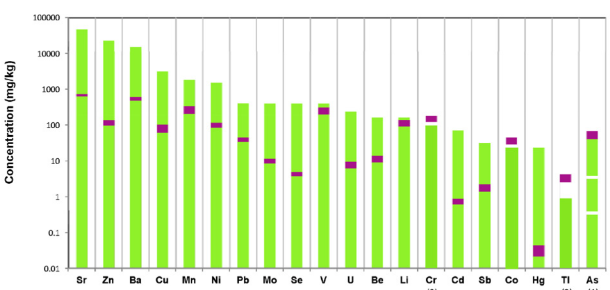
New Mexico Fly Ash



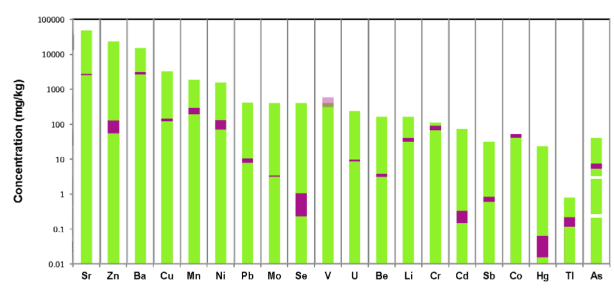
Ohio Bottom Ash



Ohio Fly Ash



Wyoming Bottom Ash



■ Concentration Range (10th - 90th Percentile) in Wyoming Bottom Ash; USGS 2011
http://pubs.usgs.gov/ds/635/

■ Top of bar corresponds to the USEPA Regional Screening Level (RSL) - Residential Soil (May 2012)
http://www.epa.gov/region9/superfund//prg/index.html

Notes:
(1) Arsenic RSLs for target risk level of 10^{-4} (top of green bar), 10^{-5} (middle white bar), 10^{-6} (lower white bar.
(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.
(3) The RSL for thallium is identified by USEPA as a "provisional value" of "limited usefulness" that was developed for information purposes although USEPA states "it is inappropriate to derive a provisional subchronic or chronic [toxicity value] for thallium" [http://hhpprtv.ornl.gov/issue_papers/ThalliumandCompounds.pdf]

Notes
RSLs: USEPA. May 2012. Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm
Ash Data: USGS. 2011. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/om

1.0 Introduction

Coal combustion products (CCPs), or coal ash, are the materials remaining after the combustion of coal. Coal is an important natural resource for our nation's economy and our energy security. Almost half of our nation's electricity is generated by burning coal according to the US Energy Information Administration (US EIA, 2012). It is estimated by the American Coal Ash Association (ACAA) that in 2010 approximately 130 million tons of CCPs were generated by 67% of the coal-fueled electric utility generation facilities, and of this amount, approximately 55 million tons, or 42.5% of CCPs were put into beneficial use (**Figure 1**) (ACAA, 2011a). These beneficial uses include the use of CCPs in concrete, gypsum wallboard, blasting grit, roofing granules, and a variety of geotechnical and agricultural applications.

There are many good reasons to view coal ash as a resource, rather than a waste. When it replaces raw materials, recycling coal ash conserves natural resources and saves energy. In many cases, products made with coal ash perform better than products made without it. For instance, coal ash makes concrete stronger and more durable. It also reduces the need to manufacture cement, resulting in significant reductions in greenhouse gas emissions; for every ton of fly ash used to replace cement in concrete, approximately 0.7 ton of greenhouse gas emissions are avoided (USEPA, 2008). Based on the ACAA Production & Use Survey results (ACAA, 2011b), approximately 11 million tons of greenhouse gas emissions were avoided by using coal ash to replace cement in 2010 alone.

This is a remarkable recycling success story. Throughout the 1990s, CCP recycling rates were in the 20% range. In 2000, when the recycling rate was 29.7%, the US Environmental Protection Agency (USEPA) issued its Final Regulatory Determination that regulation of coal ash as a "hazardous waste" was not warranted (USEPA, 2000). This provided the CCP beneficial use industry the certainty it needed to expand markets and develop new applications. Standards were developed by ASTM and the American Concrete Institute (ACI) for the use of fly ash and other CCPs in construction applications. Over the next eight years, USEPA also began actively promoting the beneficial use of coal ash and the recycling rate soared to 44.3% in 2009, in spite of steadily increasing volumes of the amount of CCPs produced (**Figure 2**) (ACAA, 2011b).

However, in the last few years, CCP recycling has seen a decline, as reported by the 2010 ACAA Production & Use Survey Report (ACAA, 2011a). This has occurred in response to USEPA's announcement in early 2009 that it would revisit its regulatory determination for CCPs (US Senate, 2009), and its co-proposals in early 2010 to regulate coal ash, with one option to regulate CCPs as a hazardous waste under Subtitle C of the Resource Conservation and Recovery Act (RCRA) (USEPA, 2010a). Even the proposal of a hazardous waste classification has stigmatized the industry, with specifiers and owners removing CCPs from projects until a final determination is made by USEPA (see examples at Citizens for Recycling First, 2012). As of 2010, the CCP recycling rate had dropped to 42.5%, even during an economic downturn when historically the use of cost-effective recycled materials increases.

Further fueling this stigma is the campaign against CCPs, and in fact coal as a fuel source, by environmental nongovernmental organizations (ENGOs). These have been led most notably by Earth Justice [http://earthjustice.org/our_work/campaigns/coal-ash-contaminates-our-lives], the Environmental Integrity Project [http://www.environmentalintegrity.org/], the Sierra Club Beyond Coal campaign [http://www.beyondcoal.org/], and Physicians for Social Responsibility [http://www.psr.org/environment-and-health/code-black/coal-ash-toxic-and-leaking.html]. News stories, blogs, and reports generated by these groups consistently refer to CCPs as “toxic coal ash,” as a “highly toxic waste stream,” and state that “coal ash is plainly and simply hazardous to your health.” These groups state that the mere presence of constituents such as arsenic, lead, mercury, cadmium, chromium and selenium in coal ash will result in adverse health effects, but none of these sources address the important relationship between exposure and response, and the more important issue of whether exposure occurs at all. None of these groups have supported their claims with a health risk analysis of the concentrations of constituents present in coal ash.

Data on constituent concentrations in various types of coal ash have been collected by the Electric Power Research Institute (EPRI), and the results were compared to constituent concentrations in natural materials and several manufacturing by-products, including soils, rocks, fertilizers, metal slags, biosolids, and spent foundry sands (EPRI, 2010). The results were also compared to USEPA human health risk-based screening levels for residential soils, and indicated that fly ash and bottom ash concentrations are largely below levels of concern. Unfortunately, the availability of this information has not had an impact on the ENGO dialog.

The US Geological Survey (USGS) recently published a study titled “Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States” (USGS, 2011). One of the goals of the USGS study was to follow the flow of coal through a power plant and determine how major, minor, and trace elements are distributed in the feed coal, the resulting changes in composition as coal is processed, and the chemical composition of the various CCPs. Five power plants in five states that utilize coal from major coal basins in the United States were selected for the study. The USGS study provides scientifically robust datasets for concentrations of trace elements present in CCPs, including those elements most often cited in ENGO literature.

1.1 Study Objective

In light of these new data developed by a governmental agency on the constituent concentrations present in CCPs from a variety of power plants and coal sources, ACAA commissioned AECOM Technical Services (AECOM) to conduct a human health risk-based evaluation of the CCP data published by the USGS (2011). The USGS collected samples of coal and CCPs at different points in the coal processing and combustion process at each power plant. The purpose of this study for ACAA is to evaluate the CCP data in the context of beneficial use. Therefore, this evaluation focuses on USGS data for the CCP materials from each facility that would likely be put into beneficial use, i.e., the final CCP product from each facility.

This evaluation takes a worst-case approach by assuming that exposure to CCPs put into beneficial use could be at the same level and intensity as that of a resident child and adult’s exposure to soils in a backyard setting. In the majority of beneficial use settings, exposure would be far less than that assumed for the residential scenario used here. Therefore, this assumption provides for a conservative evaluation of potential risk for CCP beneficial uses.

This report provides the results of this risk-based evaluation. ACAA has undertaken this evaluation to help inform the public, regulators, legislators, and the ENGOs on the potential for health risks associated with the beneficial use of CCPs.

1.2 Study Methods

The USGS report (2011) provides quantitative concentration data for major, minor, and trace elements in CCPs. This study for ACAA focuses on the trace element concentrations results. Two methods have been used to conduct the human health risk-based evaluation of the USGS CCP data.

- **RSL Comparison** - In the first, simple summary statistics are calculated for each constituent in each CCP dataset, and the results are compared to human health risk-based screening levels for residential soil developed by USEPA, called Regional Screening Levels (RSLs) (USEPA, 2012a). The RSLs combine default residential assumptions for exposure and chemical-specific dose-response values to develop screening levels for soil that are protective of residential land use. Thus, if CCP constituent concentrations are lower than the RSLs, there is no potential for adverse health effects or risk. In addition, CCP data are also compared to background soil data for the US compiled by EPRI (2010) from USGS sources.
- **Cumulative Screen** - In the second method, the CCP constituent data are statistically summarized using specific USEPA methods for risk assessment, and are used in a cumulative risk screening process, also based on the USEPA RSLs (USEPA, 2012a), and on USEPA guidance (USEPA, 2012c).

Details of these methods are provided in later sections of the report.

The evaluation presented in this report is based on the USEPA's RSLs for residential soil, which were developed following USEPA guidance for risk assessment. The RSLs are constituent concentrations in soils in units of milligrams of constituent per kilogram of soil (mg/kg). As noted by USEPA (USEPA, 2012d), RSLs are risk-based concentrations derived from standardized equations combining exposure information assumptions with USEPA toxicity data. RSLs are considered by the Agency to be protective for humans (including sensitive groups) over a lifetime, i.e., the residential soil RSLs are levels that a protective of a child and adult's daily exposure to constituents present in soil or a solid matrix over a residential lifetime. For example, for regulatory decision making, at sites where constituent concentrations fall below RSLs, no further action or study is warranted under the Superfund program.

To get a full understanding of this evaluation, it is important to understand the RSLs and their development in the context of the risk assessment process. Therefore, this evaluation is presented following the four-step risk assessment paradigm as developed by the USEPA (USEPA, 1989). The steps are:

- Data Evaluation and Hazard Identification
- Dose-Response Assessment
- Exposure Assessment
- Risk Characterization

1.3 Report Organization

A summary of the information presented in each of the remaining sections of the report follows:

- **Section 2.0** – Data Evaluation and Hazard Identification. This section presents a summary of the data available from the USGS (2011) report, and other sources, identifies the method of selection of data to include in the evaluation, and provides the summary statistics for each dataset. All detected constituents within each trace element dataset, and for which RSLs are available, are included in the evaluation.

- **Section 3.0** – Regional Screening Levels. This section provides an overview of the RSLs, to provide the necessary context for the information provided in **Sections 4 and 5**.
- **Section 4.0** – Dose-Response Assessment. The dose-response assessment evaluates the relationship between the magnitude of exposure (dose) and the potential for occurrence of specific health effects (response) for each constituent. Both potential carcinogenic and noncarcinogenic effects are considered. This section discusses the dose-response values used by USEPA in their RSL tables (USEPA, 2012a).
- **Section 5.0** – Exposure Assessment. The purpose of the exposure assessment is to provide a quantitative estimate of the magnitude and frequency of potential exposure to constituents for a receptor, in this case, a residential child and adult. For this evaluation, the standard default residential exposure scenario used by USEPA in their RSL tables is employed (USEPA, 2012a). This section identifies the conservative exposure assumptions used by USEPA in the calculation of the RSLs.
- **Section 6.0** – Risk Characterization. Risk characterization integrates the results of the exposure assessment and the dose-response assessment to derive estimates of potential carcinogenic risks and noncarcinogenic hazards resulting from the conservative residential exposure scenario. The risk characterization presents the results of the simple comparison of CCP constituent summary statistics to the USEPA RSLs for residential soil (USEPA, 2012a), and provides the detailed risk results of the cumulative risk screening conducted using the USEPA RSLs for residential soil. The results of the risk characterization are evaluated in the context the USEPA target risk range of 1×10^{-6} to 1×10^{-4} for potential carcinogens and the target Hazard Index (HI) of 1 for noncarcinogens (that act on the same target organ), as defined in USEPA guidance (USEPA, 1991). This section also provides a discussion of the uncertainties associated with the analyses and results.
- **Section 7.0** – Conclusion. This section summarizes the results and provides context for the conclusions.
- **Section 8.0** – References. This section presents the references used in the text.

Tables and figures are presented in separate sections at the end of the text, and are numbered sequentially. Appendices are presented at the end of the document. This report also provides supplemental information as a second document. Listings of the tables, figures, acronyms, chemical symbols, appendices, and supplements are provided at the end of the Table of Contents.

2.0 Data Evaluation and Hazard Identification

This section provides a description of CCPs, introduces the USGS report (USGS, 2011), describes the selection of the USGS datasets that are included in this evaluation, discusses the statistical summaries of the data, and provides some context for understanding the constituent concentrations.

2.1 Description of CCPs

Coal is a sedimentary rock that is natural component of the earth's crust. Coal contains inorganic minerals and elements in addition to its organic content. It is the organic content of coal that is burned; it is the inorganic minerals and elements that remain after combustion. The latter material is called coal ash or coal combustion products, or CCPs. There are four different types of CCPs, and their classification is based on how and when they are generated during the coal combustion process. Bottom ash and boiler slag settle to the bottom of the combustion chamber. Fly ash is also generated in the combustion chamber, but it is lighter and finer than the bottom ash and boiler slag and so is transported in the flue gas and ultimately collected by air emission controls (e.g., electrostatic precipitators or other gas scrubbing systems) (USGS, 2001). To control sulfur oxide emissions, flue gas may also be passed through a scrubber where, in the process of desulfurization, sulfur oxides are removed from the gas by reactions with a sorbent, such as limestone, lime, or less frequently, ammonia. In this process, flue gas desulfurization (FGD) products are formed (USGS, 2001). Photographs of the four different types of CCPs are shown on **Figure 3**.

Below are composite descriptions for fly ash, bottom ash, boiler slag, and FGD products from a number of sources (Kalyoncu, 1999; USGS, 2001; Office of Surface Mines (OSM); and the Coal Ash Resources Research Consortium (CARRC)).

2.1.1 Fly Ash

Fly ash is coal ash that exits from a combustion chamber in the flue gas and is captured by air pollution control equipment, such as electrostatic precipitators, baghouses, or wet scrubbers. Fly ash is a fine powder formed from the mineral matter in coal plus a small amount of unburned carbon that remains from incomplete combustion. It is composed primarily of very small, amorphous, glassy spheres of alumina and silica oxides. It is generally light in color and consists mostly of silt-sized and clay-sized glassy spheres. The consistency of fly ash resembles talcum powder.

Fly ash has cementitious and/or pozzolanic properties that make it attractive as a building material. Fly ash with a high calcium content is cementitious, meaning that it will harden like concrete when mixed with water. Cementitious ashes are typically generated from low sulfur, western coals. Fly ash with lower calcium content is said to be pozzolanic, meaning that it will harden when mixed with both calcium and water. Pozzolanic ashes are typically generated from high-sulfur, eastern and mid-western coals.

2.1.2 Bottom Ash

Bottom ash consists of agglomerated ash particles that are too large to be carried in the flue gases and instead adhere to the boiler walls or fall through open grates to an ash hopper at the bottom of the boiler. Bottom ash is typically a gray to black, coarse, granular material with a porous surface texture.

Bottom ash is coarser than fly ash with grain sizes ranging from fine sand to fine gravel (3/8-inch). It is usually a small portion of the total ash produced by the boiler.

2.1.3 Boiler Slag

Boiler slag is similar to bottom ash, but represents material that has been melted during combustion in cyclone boilers. It is collected at the base of the boilers and is quenched with water causing it to shatter into black, angular particles that have a smooth glassy appearance. Boiler slag is generally a black, granular, vitreous material and is coarser than fly ash.

2.1.4 FGD Gypsum

FGD products are generated from the process of removing sulfur dioxide (SO_2) from flue gas using a sorbent such as lime, limestone, or ammonia. In the United States, 90% of FGD systems use lime or limestone (USGS, 2001). FGD sludge is commonly combined with fly ash to dry and stabilize the material. The physical nature of these materials varies from a wet sludge to a dry, powdered material, depending on the process.

2.2 USGS Report

The USGS (2011) report titled "Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States" provides concentration data for constituents in CCPs. The material accompanying the 2011 USGS report includes analytical data on a suite of metals and inorganics in coal and various types of coal ash from five coal-fired power plants in the US in the states of: Alaska, Indiana, New Mexico, Ohio, and Wyoming. The coals used by these plants represent the major coal basins in the US. **Table 1** provides a summary of the CCP data available from the USGS report. The table identifies the state where the power plant is located, the type of coal that is used, and the types of CCPs for which constituent data are available. CCP data for fly ash and bottom ash are provided in the report. It does not appear that boiler slag is a material produced by any of these power plants. As only one sample each of gypsum and sludge (FGD products) were collected (from the Indiana Power Plant), these were not included in this evaluation. The USGS report does not identify the names of the participating power plants; however, AECOM is familiar with the Alaska Power Plant, and the evaluation presented here of the USGS study data uses additional information obtained from that plant.

2.3 Dataset Selection

While the purpose of the USGS study was to "follow" constituents through the power plant from the coal to the final materials produced, the focus of this study for ACAA is to evaluate the CCP data in the context of beneficial use. Therefore, the risk-based analysis focuses on the CCPs from each plant that could or would be used beneficially. The types of CCPs sampled and where they were collected from within each power plant process were reviewed as part of the dataset selection process. **Appendix A** provides the operational schematics for each of the power plants, as obtained from the USGS report. Each power plant is discussed below. However, it should be noted that because the specific power plants are not identified, it is unknown whether or not these CCPs are actually put into beneficial use (with the exception noted above).

Note that while it would have been interesting to conduct this analysis on all of the CCP datasets collected by USGS, this was out of the scope of this project. Moreover, because many of the datasets represent steps in the CCP generation process and not the final product, these data are not germane to the evaluation of beneficial use.

2.3.1 Alaska Power Plant

Five types of CCPs are represented in the USGS database for the Alaska Power Plant, as shown on **Table 1**. At this plant, the fly ash and bottom ash are mixed in the ash silo (see the schematic in **Appendix A**), and it is this mixed material that is used beneficially, based on discussion with the power plant personnel. Therefore, the USGS data for the “fly ash silo” (fly ash/bottom ash mix) are used in this analysis.

2.3.2 Indiana Power Plant

The USGS sampled six types of CCPs from the Indiana Power Plant, as shown on **Table 1**. The Indiana Power Plant schematic is shown in **Appendix A**. It is clear from the schematic that the Economizer Fly Ash samples and the Air Preheater Ash samples are from intermediate steps in the fly ash collection process for this plant and do not represent materials that are isolated or separately produced or that could be put into beneficial use. Therefore, the USGS data for “fly ash” are used in this analysis, as it likely represents what could be put into beneficial use. USGS obtained only one sample each of bottom ash, gypsum, and sludge from the Indiana Power Plant, so these materials from this plant are not included in this analysis.

2.3.3 New Mexico Power Plant

The USGS provides data for five types of CCPs for the New Mexico Power Plant, as shown on **Table 1**. The New Mexico Power Plant schematic is shown in **Appendix A**. Bottom ash is removed from the boiler separately; therefore, the bottom ash data are included in this analysis. It is clear from the schematic that the “north fly ash” and “south fly ash” samples are from intermediate steps in the fly ash collection process for this plant, therefore, they are not included in this analysis. The fly ash processing facility produces two materials: fly ash (coarse), and fly ash (product). As the term “product” is indicative of beneficial use, the USGS data for fly ash (product) are used in this analysis. It should be noted that a comparison of the fly ash (product) and the fly ash (coarse) constituent concentrations indicates that that the fly ash (product) constituent concentrations are generally higher; thus, this selection is conservative. USGS data summary tables for coal ash materials not included in this evaluation are provided in **Supplement A**.

2.3.4 Ohio Power Plant

The USGS sampled three types of CCPs from the Ohio Power Plant, as shown on **Table 1**. The Ohio Power Plant schematic is shown in **Appendix A**. Bottom ash is removed from the boiler separately; therefore, the bottom ash data are included in this analysis. It is clear from the schematic that the Economizer Fly Ash samples are from an intermediate step in the fly ash collection process for this plant and do not represent material that is isolated or separately produced or that could be put into beneficial use. Therefore, the USGS data for “fly ash” are used in this analysis.

2.3.5 Wyoming Power Plant

The USGS sampled three types of CCPs from the Wyoming Power Plant, as shown on **Table 1**. The Wyoming Power Plant schematic is shown in **Appendix A**. Bottom ash is removed from the boiler separately; therefore, the bottom ash data are included in this analysis. It is clear from the schematic that the Economizer Fly Ash samples are from an intermediate step in the fly ash collection process for this plant and do not represent material that is isolated or separately produced or that could be put into beneficial use. Therefore, the USGS data for “fly ash” are used in this analysis.

2.3.6 Summary

Table 2 provides a summary by power plant of the coal used, the CCP dataset used in this risk-based evaluation, and the number of samples in each dataset.

2.4 USGS Constituent Data

The material accompanying the 2011 USGS report includes analytical data on a suite of metals and inorganics in the CCPs sampled.

2.4.1 Analytical Methods

The USGS reports that most element concentrations were determined by inductively coupled plasma mass spectroscopy (ICPMS) (As, Be, Bi, Cd, Co, Cr, Cs, Cu, Ga, Ge, Li, Mn, Mo, Nb, Ni, Pb, Rb, Sb, Sc, Th, Tl, U, V, Y, and Zn) or by inductively coupled plasma atomic emission spectroscopy (ICPAES) (SiO_2, Al_2O_3, CaO, MgO, Na_2O, K_2O, Fe_2O_3, TiO_2, P_2O_5, SO_3, Ba, and Sr). Elemental chemical symbols are defined on a list following the Table of Contents, and on **Figure 6**. Mercury was analyzed by the direct mercury (Hg) analyzer (DMA80), selenium (Se) was analyzed by hydride generation atomic absorption (AAnalyst200), chorine (Cl) was analyzed by the total chlorine analyzer (TOX-100), and sulfur (S) was analyzed by the LECO SC 632. Boron was not included on the USGS analyte list.

2.4.2 USGS Summary Statistics

Data on fly ash from the five states and bottom ash from New Mexico, Ohio and Wyoming are included in this risk-based screening evaluation and have been evaluated separately, and in combination. Alaska and Indiana were not evaluated for bottom ash alone; the USGS obtained only one sample of bottom ash for the Indiana plant, and the Alaska plant mixes the bottom ash and fly ash for beneficial use, and the data for the mixture have been evaluated, and has been included in the "Fly Ash" grouping for the purposes of this report.

USGS provides summary tables for each of the datasets. These have been reproduced in **Appendix B**, which includes:

- USGS Table 14 – Alaska Fly Ash/Bottom Ash
- USGS Table 18 – Indiana Fly Ash
- USGS Table 20 – New Mexico Bottom Ash
- USGS Table 24 – New Mexico Fly Ash Product
- USGS Table 28 – Ohio Bottom Ash
- USGS Table 30 – Ohio Fly Ash
- USGS Table 34 – Wyoming Bottom Ash
- USGS Table 36 – Wyoming Fly Ash

For each constituent, the USGS tables provide the number of samples analyzed and the following statistics on the concentration data: mean, median, minimum, maximum, and standard deviation.

The USGS provides information on major, minor, and trace elements in the CCPs. This risk-based evaluation focuses on the trace elements. The sample-by-sample results for the trace elements available in the USGS materials accompanying the report are presented in **Appendix C**. Only results for the 20 constituents for which USEPA provides a risk-based RSL (USEPA, 2012a) are shown. Additional details on various aspects of the RSLs are discussed in **Sections 3, 4 and 5**. For completeness, the USGS summary tables for the datasets not included in this evaluation are presented in **Supplement A** to this report.

2.4.3 Percentiles

While the statistical summaries provided by USGS are informative, the mean and standard deviation are useful only when a dataset is normally distributed. Percentiles calculated from the data provide simple and easily reproducible statistics for a dataset. For example, at the 90th percentile level, 10% of the data are above that level, and 90% of the data are below that level.

Statistics were calculated using the USEPA risk assessment statistical program ProUCL version 4.1.01 (USEPA, 2011). ProUCL percentile calculations do take into account the underlying distribution of the dataset. ProUCL does not calculate summary percentiles for datasets with non-detect values. Therefore, for constituents that were detected but that had one or more non-detected sample results, percentiles were calculated using Microsoft Excel® for detected values only (this was necessary for several constituents in each of the three bottom ash datasets).

The summary statistics as calculated by USEPA's ProUCL program for the concentrations of the 20 constituents in fly ash and bottom ash from the five coal-fired power plants for which USEPA RSLs are available are presented in **Tables 3 through 7** for fly ash datasets and **Tables 8 through 10** for bottom ash. **Table 11** provides summary statistics for the fly ash data for all five states combined, and **Table 12** provides summary statistics for the bottom ash data for three states (New Mexico, Ohio, and Wyoming) combined. For each constituent for which there is a USEPA RSL (USEPA, 2012a), the following are provided: frequency of detection (FOD), minimum detected concentration, maximum detected concentration, mean detected concentration, median, 10th percentile, 50th percentile, and 90th percentile concentrations.

Additional statistics calculated for the cumulative screen evaluation are discussed in **Section 5**.

2.5 Constituent Concentrations in Context

The USGS tables presented in **Appendix B** provide the CCP make-up of the major, minor, and trace elements in the CCPs. It is important to understand that the constituents that are the focus of risk-based evaluations of CCPs are the trace elements and these are called trace because they are present in such low concentrations (in the mg/kg or part per million range) in both CCPs and in native soils (EPRI, 2010). Other elements are present at higher concentrations; major elements make up the majority of the chemical content, with minor elements present at lower concentrations (but still higher than trace elements).

The USGS data tables provide the concentration (in percent) of some of the major and minor elements (as oxides) at the top of each data table (**Appendix B**). The data shown in **Table 13** summarize this information for the mean or average percent for the CCPs that are the focus of this evaluation. The total mean percent for these major and minor elements in each CCP is also presented in **Table 13**; these range from 93 percent to over 99 percent, leaving on average 2-3 percent for the trace component.

For example, SiO_2 (silicon dioxide) is present at 45.3 percent for the mean concentration in the Alaska Power Plant Fly Ash/Bottom Ash, which is equivalent to 453,000 mg/kg or parts per million. The highest mean trace element concentration in the Alaska Power Plant Fly Ash/Bottom Ash is 4,959 mg/kg for barium (100-fold lower), with the majority of the constituents present well below 1,000 mg/kg (for example, the mean concentration for molybdenum is 34.35 mg/kg and for mercury is 0.46 mg/kg) (see **Table 3**).

To put these concentrations into context, a mg/kg or a part per million (ppm) are equivalent to:

- 1 penny in a stack of $10,000
- 1 second in 11.5 days
- 1 inch in 15.8 miles

For additional context, 15.8 miles is the distance from the Capitol Building in Washington, DC to a location roughly between Tyson's Corner, VA and Vienna, VA. This is shown on **Figure 4**. Using this analogy, the trace elements in CCPs may take you a few inches away from the Capitol Building, and for barium a little over a football field away (so part way down the National Mall), and the rest of the distance into Virginia is made up of the major and minor elements.

These trace elements are also present naturally in soils in the US, and this is how they came to be present in the coal. **Table 14** provides a summary of background concentration data for US soils derived from USGS sources by EPRI (EPRI, 2010). Note that data are not available for all of the constituents included in the USGS CCP study. USGS is also conducting a National Geochemical Survey (USGS, 2012) of elemental concentrations in US soils. Currently, results for 14 elements are posted on their website (http:// mrdata.usgs.gov/geochem/doc/averages/countydata.htm). **Figure 5** provides the USGS maps for arsenic, mercury, selenium and lead.

Because these constituents are present in soils naturally, they are also present in the foods we eat, as plants take up these elements from the soil. The Agency for Toxic Substances and Disease Registry (ATSDR), a federal public health agency of the U.S. Department of Health and Human Services, is a good source for information on background levels of constituents in our food supply (http://www.atsdr.cdc.gov/toxprofiles/index.asp).

The remaining sections of this report addresses the concentrations of trace constituents in the CCPs as reported by USGS, focusing on the 20 for which USEPA has developed residential soil RSLs. These are:

- Sb – Antimony
- As – Arsenic
- Ba – Barium
- Be – Beryllium
- Cd – Cadmium
- Cr – Chromium
- Co – Cobalt
- Cu – Copper
- Pb – Lead
- Li – Lithium

- Mn – Manganese
- Hg – Mercury
- Mo – Molybdenum
- Ni – Nickel
- Se – Selenium
- Sr – Strontium
- Tl – Thallium
- U – Uranium
- V – Vanadium
- Zn – Zinc

3.0 Regional Screening Levels

USEPA's regional screening levels (RSLs) are human health risk-based screening levels developed for various environmental media (soil, air and water) (USEPA, 2012a). Risk-based RSLs are derived from equations combining exposure assumptions with chemical-specific dose-response values, using a specified target risk level.

In very simple terms, risk is a function of exposure and toxicity:

Risk = Exposure x Toxicity

Exposure is a function of the constituent concentration in an environmental medium, and the assumptions for contacting the constituent, which are then used to define the level of exposure to a constituent in an environmental medium:

Exposure = Concentration x Exposure Factors

Thus risk can be expressed as:

Risk = Concentration x Exposure Factors x Toxicity

One can use this relationship to calculate a concentration level of a constituent in an environmental medium that correlates to a specific target risk level:

$$\text{Concentration} = \frac{\text{Target Risk}}{\text{Exposure Factors x Toxicity}}$$

RSLs are concentrations of constituents in environmental media that have been derived based on generic or default assumptions about exposure, currently available dose-response information, and default target risk levels; thus, combining the aspects of the 4-step risk assessment paradigm discussed in **Section 1**. USEPA uses this relationship to calculate RSLs for residential soil, industrial soil, residential air, industrial air, and tap water or drinking water (USEPA, 2012a).

For this evaluation, the RSLs for residential soil have been used. For the calculation of the residential soil RSLs, USEPA assumes that a residential receptor could be exposed to constituents in soil on a daily basis in a residential setting via several exposure pathways (USEPA, 2012c):

- Incidental ingestion of soil,
- Inhalation of particulates emitted from soil as dust, and
- Dermal contact with soil.

By comparing the USGS data for constituent concentrations in CCPs to residential soil RSLs, the assumption is made that a resident would be exposed to CCPs rather than soil on a daily basis.

The RSLs used in this evaluation are provided in **Table 15**. USEPA also provides supporting tables for each medium (soil, air, etc.) that detail the RSL derivations (USEPA, 2012a). Where a constituent has dose-response values available for both potentially carcinogenic and noncarcinogenic effects, the supporting RSL tables provide RSLs based on each endpoint. Several of the constituents included in this evaluation have RSLs calculated for each endpoint (the potentially carcinogenic component and the noncarcinogenic component), and these are also provided in **Table 15**.

As noted above, two separate evaluations of the USGS data are provided in this report.

- In the “RSL Comparison,” the calculated percentiles are compared directly to the RSLs as published by USEPA and shown on **Table 15**.
- In the “Cumulative Screen,” the RSLs calculated for each endpoint (the potentially carcinogenic component and the noncarcinogenic component) on **Table 15** are used.

To provide context to the dose-response component of the RSLs, and to allow for an understanding of the conservative, i.e., health-protective, nature of the residential soil screening levels provided in the RSL table, **Section 4** provides information on the derivation of dose-response values used by USEPA, and the exposure assumptions used in the derivation of the RSLs are discussed in **Section 5**.

4.0 Dose-Response Assessment

The purpose of the dose-response assessment is to identify the types of adverse health effects a constituent may potentially cause, and to define the relationship between the dose of a constituent and the likelihood and magnitude of an adverse effect (response) (USEPA, 1989). This dose-response relationship is the foundation of toxicology and of medicine.

Within regulatory risk assessment, adverse effects are classified by USEPA as potentially carcinogenic or noncarcinogenic (i.e., potential effects other than cancer). Dose-response relationships are defined by USEPA for oral exposure and for exposure by inhalation. Oral dose-response values are also used to assess dermal exposures, with appropriate adjustments, because USEPA has not yet developed dose-response values for this route of exposure (USEPA, 1989). Combining the results of the dose-response assessment with information on the magnitude of potential human exposure provides an estimate of potential risk (USEPA, 1989).

4.1 Dose-Response Value Overview

The Integrated Risk Information System (IRIS) (USEPA, 2012b) is USEPA's online database of dose-response values. These values address both potentially carcinogenic and noncarcinogenic effects and are peer reviewed following extensive scientific study and review prior to finalization. The values serve as the primary toxicity data used in the US.

4.1.1 Noncancer Effects

As stated in IRIS (USEPA, 2012b), for noncancer effects, oral reference doses and inhalation reference concentrations (RfDs and RfCs, respectively) for effects known or assumed to be produced through a nonlinear (threshold) mode of action are developed. Simply stated, the threshold is the exposure below which no adverse effects are seen, and above which adverse effects may be seen. As exposure increases above the threshold, more types of effects may occur and/or the severity of effects may increase. As a simple example, 1-2 tablets of aspirin can be taken safely every four hours on a daily basis, but consuming an entire bottle of aspirin at one time can be fatal.

The noncancer oral Reference Dose (RfD) is based on the assumption that thresholds exist for certain adverse effects, for example liver effects. The RfD is expressed in units of milligrams of constituent per kilogram of body weight per day (mg/kg-day). In general, the RfD is an estimate of the threshold (with uncertainty spanning perhaps an order of magnitude) of a daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

4.1.2 Potentially Carcinogenic Effects

As stated in IRIS (USEPA, 2012b), for potential cancer effects, descriptors that characterize the weight of evidence for human carcinogenicity, oral slope factors, and oral and inhalation unit risks for carcinogenic effects are developed. The quantitative risk estimates are presented in two ways. The oral slope factor (SFO) is the result of application of a low-dose extrapolation procedure and is presented as the risk per (mg/kg-day). The inhalation unit risk (IUR) is the quantitative estimate in terms of either risk per microgram per liter (µg/L) drinking water or risk per microgram per cubic meter (ug/m^3) air breathed. The derivation of these values assumes there is no threshold for effects. This concept is discussed in more detail in **Section 4.4**.

As noted by USEPA (2012c), an SFO or IUR and the accompanying weight-of-evidence determination are the dose-response data most commonly used to evaluate potential human carcinogenic risks. The slope factor is defined as a plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. The slope factor is used in risk assessments to estimate an upper-bound lifetime probability of an individual developing cancer over the background rate as a result of exposure to a particular level of a potential carcinogen, understanding that due to model uncertainties the risk could be as low as zero.

4.1.3 Dose-Response Value Derivation

Numerical dose-response values are generally obtained from USEPA databases/sources, as described in **Section 4.2**. The dose-response relationship is often determined from laboratory studies conducted under controlled conditions with laboratory animals. These laboratory studies are controlled to minimize responses due to confounding variables, and are conducted at relatively high dose levels to ensure that responses can be observed using as few animals as possible in the experiments. Mathematical models or uncertainty factors are used to extrapolate the relatively high doses administered to animals to predict potential human responses at dose levels far below those tested in animals.

Humans are typically exposed to constituents in the environment at levels much lower than those tested in animals. These low doses may be detoxified or rendered inactive by the myriad of protective mechanisms that are present in humans (Ames, et al., 1987) and which may not function at the high dose levels used in animal experiments. Moreover, as noted by USEPA (USEPA, 1993) "in the case of systemic toxicity, however, organic homeostatic, compensating, and adaptive mechanisms exist that must be overcome before a toxic endpoint is manifested." Therefore, the results of these animal studies at high doses may only be of limited use in accurately predicting a dose-response relationship in humans at low doses (USEPA, 1989). However, to be protective of human health, USEPA incorporates conservative assumptions and safety factors when deriving numerical dose-response values from laboratory studies, as discussed below. USEPA explicitly recognizes these extrapolations from high doses to low doses and from animal studies to predict responses in humans as uncertainties in the risk assessment process (USEPA, 1989).

In some cases, data from human exposure to constituents are used to develop dose-response values. However, these data also have uncertainties because it is not possible to determine from human exposure studies whether one or more constituents are responsible for the observed effects, and in general it is even more difficult to determine precise exposure levels (USEPA, 1989). Moreover, where effects are observed in humans, they generally occur at high exposure levels (often in industrial settings), and it is difficult to predict potential human responses at the much lower dose levels that occur in environmental exposure scenarios (USEPA, 1989). Many of the inhalation dose-response values are derived from occupational exposure studies at high exposure levels and, there are cases where human toxicity has been observed at high site-specific environmental levels, for example cases of arsenic exposure in Taiwan or Bangladesh (Hughes, et al., 2011).

4.2 Sources of Dose-Response Values

The USEPA provides guidance regarding the hierarchy of sources of human health dose-response values in risk assessment (USEPA, 2003). Understanding this hierarchy is important for several of the constituents included in this analysis.

- The primary (Tier 1) USEPA source of dose-response values is IRIS, an on-line computer database of toxicological information (USEPA, 2012b). The IRIS database is updated regularly to provide the most current USEPA verified dose-response values. As defined by the USEPA (1997), a dose-response value is “Work Group-Verified” if all available information on the value has been examined by an Agency Work Group, the value has been calculated using current Work Group methodology, a unanimous consensus has been reached on the value by the Work Group, and the value appears on IRIS.
- When a Tier 1 dose-response value is not available from IRIS, Tier 2 values are used, which are the provisional peer-reviewed toxicity values (PPRTVs) or other provisional values published by the USEPA National Center for Environmental Assessment (NCEA) in Cincinnati.
- If dose-response values are not available from IRIS (Tier 1) and PPRTVs are not available (Tier 2), a Tier 3 source is used. Tier 3 sources include: Agency for Toxic Substances Disease Registry (ATSDR) Minimal Risk Levels (MRLs) (ATSDR, 2012), California Environmental Protection Agency (CalEPA) values (CalEPA, 2008; 2012), or USEPA’s Health Effects Assessment Summary Tables (HEAST) (USEPA, 1997). The EPA RSL tables use these Tier 3 sources in the order presented (USEPA, 2012c). In addition, pertinent to this evaluation, the RSL table uses a dose response value obtained for hexavalent chromium from the New Jersey Department of Environmental Protection (NJDEP) (NJDEP, 2009).

In general, the Tier 3 sources are considered to be an unverified source of dose-response values and should be used only if no dose-response value is available from IRIS or the NCEA. Therefore, the hierarchy of dose-response value sources correlates in general with the level of confidence in the values, with the values provided by IRIS or NCEA having the higher level of confidence. While the other Tier 3 sources (i.e., ATSDR, CalEPA, NJDEP) may provide more current dose-response values than HEAST, these values are also considered to have a lower level of confidence than the USEPA-derived values due to the differences in derivation and review processes.

4.3 Noncarcinogenic Dose-Response Assessment

The noncancer dose-response values are an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily oral or inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime.

Constituents with known or potential noncarcinogenic effects are assumed to have a dose below which no adverse effect occurs or, conversely, above which an adverse effect may be seen. This dose is called the threshold dose. A conservative estimate of the true threshold dose is called a No Observed Adverse Effect Level (NOAEL). The lowest dose at which an adverse effect has been observed is called a Lowest Observed Adverse Effect Level (LOAEL). The NOAEL, or if not available, the LOAEL is used as the point of departure (POD) for extrapolating from experimental data to predict a threshold level for humans. By applying uncertainty factors to the NOAEL or the LOAEL, oral Reference Doses (RfDs) or inhalation Reference Concentrations (RfCs) for chronic exposure to constituents with noncarcinogenic effects have been developed by USEPA (1997, 2012b).

In more recent derivations, USEPA has used a benchmark dose (BMD) approach to define the POD for an observed adverse outcome, or benchmark response, from experimental observations (USEPA, 2012f). The BMD approach provides a more quantitative alternative to the first step in the dose-response assessment than the current NOAEL/LOAEL process for noncancer health effects. Derivation of the BMD is a two-step process: (1) response data are modeled in the range of empirical observation; and then (2) extrapolation below the range of observation is accomplished by modeling. The POD for BMD modeling is the BMDL, or the lower 95% bound on the dose/exposure associated with the benchmark response (i.e., adverse response), typically 10% above the control response. Using the lower bound accounts for the uncertainty inherent in a given study, and assures (with 95% confidence) that the target benchmark response is not exceeded. Uncertainty factors are then applied to the BMDL, as in the case for the NOAEL/LOAEL approach, to derive an RfD or RfC. For example the BMD approach has been used for the derivation of the dose-response values for barium and beryllium (oral RfD), and hexavalent chromium (inhalation RfC).

The RfDs and RfCs are developed based on the most sensitive or critical adverse health effect observed in the study population, with the assumption that if the most critical effect is prevented, then all other potential toxic effects are prevented. These are referred to as the target endpoints, and are identified for the noncancer component for the constituents in this evaluation on **Table 15**. These target endpoints are an important component of the cumulative risk screening evaluation, as discussed in **Section 6**.

In regulatory dose-response assessment, USEPA assumes that humans are as sensitive, or more sensitive, to the toxic effects of a constituent as the most sensitive species used in the laboratory studies. Uncertainty factors are applied to the BMDL or NOAEL (or LOAEL, when a NOAEL is unavailable) for the critical effect to account for uncertainties associated with the dose-response relationship. These include using an animal study to derive a human toxicity value, extrapolating from a LOAEL to a NOAEL, extrapolating from a subchronic (partial lifetime) to a chronic lifetime exposure, and evaluating sensitive subpopulations. Generally, a 10-fold factor is used to account for each of these uncertainties; thus, the total uncertainty factor can range from 10 to 10,000. In addition, an uncertainty factor or a modifying factor of up to 10 can be used to account for inadequacies in the database or other uncertainties. The uncertainty factors for the dose-response values for the RSLs used in this evaluation range from 1 to 3000 (see **Table 16**). USEPA's standard uncertainty factors and the modifying factor are identified below (USEPA, 1993).

Standard Uncertainty Factors (UFs):

- A 10-fold factor is used when extrapolating from valid experimental results in studies using prolonged exposure to average healthy humans. This factor is intended to account for the variation in sensitivity among the members of the human population and is referenced as "10H".
- An additional 10-fold factor is used when extrapolating from valid results of long-term studies on experimental animals when results of studies of human exposure are not available or are inadequate. This factor is intended to account for the uncertainty involved in extrapolating from animal data to humans and is referenced as "10A".
- An additional 10-fold factor is used when extrapolating from less than chronic results on experimental animals when there are no useful long-term human data. This factor is intended to account for the uncertainty involved in extrapolating from less than chronic NOAELs to chronic NOAELs and is referenced as "10S".
- An additional 10-fold factor is used when deriving an RfD from a LOAEL, instead of a NOAEL. This factor is intended to account for the uncertainty involved in extrapolating from LOAELs to NOAELs and is referenced as "10L".

Modifying Factor (MF):

- Use professional judgment to determine the MF, which is an additional uncertainty factor that is greater than zero and less than or equal to 10. The magnitude of the MF depends upon the professional assessment of scientific uncertainties of the study and database not explicitly treated above; e.g., the completeness of the overall database and the number of species tested. The default value for the MF is 1.

The resulting RfDs and RfCs are conservative, i.e., health protective, because of the use of the uncertainty factors and modifying factors, where applicable. For constituents with noncarcinogenic effects, an RfD or RfC provides reasonable certainty that no noncarcinogenic health effects are expected to occur even if daily exposures were to occur at the RfD level for a lifetime. RfDs and exposure doses are expressed in units of milligrams of a constituent per kilogram of body weight per day (mg/kg-day). RfCs and exposure concentrations are expressed in terms of milligrams of constituent per cubic meter of air (mg/m^3). The lower the RfD or RfC value, the lower is the assumed threshold for effects, and the greater the assumed toxicity.

4.4 Carcinogenic Dose-Response Assessment

A slope factor is most commonly used to evaluate potential human carcinogenic risks. Generally, the slope factor is a plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. The slope factor is used in risk assessments to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen. USEPA has updated the carcinogen risk assessment derivation guidelines (USEPA, 2005a) that revise and replace the previous carcinogen risk assessment guidelines (USEPA, 1986).

In the previous guidance, it was assumed that there is some finite level of risk associated with each non-zero dose. The USEPA has developed computerized models that extrapolate dose-response relationships observed at the relatively high doses used in animal studies to the low dose levels encountered by humans in environmental situations. The mathematical models developed by USEPA assume no threshold, and use both animal and human data (where available) to develop a potency estimate for a given constituent. The potency estimate for oral and dermal exposure, called a cancer slope factor (SFO) is expressed in units of $(mg/kg\text{-}day)^{-1}$; the higher the SFO, the greater the carcinogenic potential. The potency estimate for inhalation exposures, called an inhalation unit risk factor (IUR), is expressed in terms of $(ug/m^3)^{-1}$ (where ug is microgram); the higher the IUR factor, the greater the carcinogenic potential. A slope factor and the accompanying weight-of-evidence determination are the toxicity data most commonly used to evaluate potential human carcinogenic risks.

The cancer dose-response values are used in risk assessments to estimate an upper-bound lifetime probability of an individual developing cancer as a result of exposure to a particular level of a potential carcinogen.

USEPA (2005a) places greater emphasis on critically evaluating all available data from which a default option may be invoked if needed in the absence of critical information. The guidance also emphasizes the use of mode of action data. Mode of action is defined as a sequence of key events and processes, starting with interaction of an agent with a cell and resulting in cancer formation. Some modes of action are anticipated to be mutagenic and are assessed with a linear approach. Other modes of action may be modeled with either linear or nonlinear approaches after a rigorous analysis of available data under the guidance provided in the framework for mode of action analysis.

While this guidance represents important advances in carcinogen risk assessment, the approach has not generally been implemented for constituents with toxicity values on IRIS, and its application has only been used for the dose-response assessment for chloroform.

USEPA has also developed guidance for early life exposure to carcinogens (USEPA, 2005b) requiring that potential risks from constituents that act by a mutagenic mode of action be calculated differently than constituents that do not act via a mutagenic mode of action. This guidance pertains only to the RSLs developed by USEPA for hexavalent chromium. This is addressed in more detail below.

4.5 Dose-Response Values Used in the RSL Tables

Table 16 lists the dose-response values from the RSL table (USEPA, 2012a) used for the constituents included in this evaluation. All of the 20 constituents included in this evaluation have noncancer dose-response values for the oral route of exposure (RfD_o) (lead is evaluated separately by USEPA using a specific exposure-effects model; USEPA, 2002b) and 11 have noncancer dose-response values for the inhalation route of exposure (RfC_i). Six of the 20 constituents are identified as potential carcinogens; only two are identified as potential carcinogens by the oral route of exposure (for which SFO values are provided), and six are classified as potential carcinogens by the inhalation route of exposure and for which IUR factors are provided. As will be discussed in more detail in **Section 5**, while the RSLs include the oral, dermal and inhalation pathways in their derivation, the final values used on the table are driven by the oral route of exposure. Thus, for the constituents that have both noncancer oral dose-response values and cancer inhalation dose-response values, the RSLs are based on the noncancer oral ingestion pathway (with the exception of hexavalent chromium).

4.6 Dose-Response Values for Specific Constituents

The dose-response values for several of the constituents included in this evaluation have additional associated uncertainties. These are discussed below.

4.6.1 Thallium

The RSL for thallium is based on information contained within a USEPA PPRTV document (USEPA, 2010b). No PPRTVs were developed due to database deficiencies. According to USEPA (2010b), a reference dose for thallium was not derived because the available toxicity database contains studies that are generally of poor quality. Appendix A of the PPRTV document indicates that it is inappropriate to derive provisional chronic or subchronic RfDs for thallium, but that information is available which, although insufficient to support derivation of a provisional toxicity value, under current guidelines, may be of limited use to risk assessors. The RfDs are based on a subchronic study in rats and the NOAEL is based on hair follicle atrophy; this endpoint was selected because atrophy of hair follicles is consistent with the atrophic changes observed in cases of human thallium poisoning and may be the best indication for human response to thallium exposure (USEPA, 2010b). However, this endpoint is not a “toxic” endpoint per se, and the results of the thallium risk assessment should be interpreted with appropriate reservations. It should be noted that the chronic oral RfD for thallium used in the RSL tale is the provisional screening value derived in Appendix A of USEPA (2010b).

ATSDR (1992) identifies that the general population is exposed most frequently by ingestion of thallium-containing foods, especially home-grown fruits and green vegetables. It is estimated that a 70 kg adult ingests 0.005 mg thallium per day in the diet. This is equivalent to a daily dose of 7E-05 mg/kg-day (0.00007 mg/kg-day). The USEPA supplemental provisional oral reference dose for thallium is 1E-05 mg/kg-day (0.00001 mg/kg-day). This is seven times <u>lower</u> than the estimated dietary intake. In other words, use of this dose-response value to evaluate natural dietary exposure to thallium would indicate a hazard that is unlikely to exist.

Despite the reservations noted in the document, this dose-response value for thallium has been used in the RSL table, with the result being that the RSL for thallium for residential soil is the lowest of all the RSLs used in this evaluation with the exception of arsenic and hexavalent chromium.

4.6.2 Cobalt

The World Health Organization (WHO) indicates that “there are no suitable data with which to derive a tolerable intake for chronic ingestion of cobalt” (WHO, 2006). ATSDR (2004) states that “adequate chronic studies of the oral toxicity of cobalt or cobalt compounds in humans and animals are not presently available.” However, using a short-term study in six human volunteers, ATSDR (2004) derived an intermediate-term (15–364 days) minimal risk level (MRL) of 0.05 mg/kg-day. The “adverse” effect was identified as increased red blood cell count, although it is also noted that cobalt is used as a treatment for anemia (low red blood cell count). ATSDR also notes that “Since cobalt is naturally found in the environment, people cannot avoid being exposed to it. However, the relatively low concentrations present do not warrant any immediate steps to reduce exposure.” WHO notes that the largest source of exposure to cobalt for the general population is the food supply; the estimated intake from food is 5–40 ug/day, most of which is inorganic cobalt (WHO, 2006). Expressed on a mg/kg-day basis, this is 0.00007–0.0005 mg/kg-day from the diet.

USEPA however has derived a PPRTV for cobalt of 0.0003 mg/kg-day, this is two orders of magnitude lower than the ATSDR intermediate term MRL, and is higher that most dietary intake estimates. Thus there is much uncertainty associated with the USEPA dose-response value for cobalt, and with the resulting RSL for residential soil.

4.6.3 Hexavalent Chromium

The data provided by USGS (2011) for chromium is for total chromium in the samples. Many metals can exist in different oxidation states; for some metals, the oxidation state can have different toxicities. This is the case for chromium. Chromium exists in two common oxidation states: trivalent chromium (chromium-3, Cr(III) or Cr+3), and hexavalent chromium (chromium-6, Cr(VI) or Cr+6). Trivalent chromium is essentially nontoxic, as evidenced by its RSL of 120,000 mg/kg. It can be bought over-the-counter as a supplement, and is included in most vitamins. Hexavalent chromium has been concluded to be a human carcinogen by the inhalation route of exposure (USEPA, 2012b).

Currently on IRIS (USEPA, 2012b), the Tier 1 source of dose-response information for risk assessment and for the RSL tables, an oral RfD is available for trivalent chromium, and IRIS provides an inhalation IUR for potential inhalation carcinogenic effects and an oral RfD and inhalation RfC for hexavalent chromium. These values are presented on **Table 16**. Note that the oral noncancer dose-response value for hexavalent chromium is based on a study where no adverse effects were reported; thus the target endpoint is identified as “none reported.”

Recent studies by the National Toxicology Program (NTP) have shown that when present in high concentrations in drinking water, hexavalent chromium can cause gastrointestinal tract tumors in mice (NTP, 2008). IRIS does not present an oral CSF for hexavalent chromium; a value developed by NJDEP (2009) was used in the development of the RSLs. USEPA developed a draft oral cancer dose-response value for hexavalent chromium, based on the same study and was the same as the NJDEP value. However, it should be noted that USEPA’s Science Advisory Board (SAB) provided comments in July 2011 on the draft USEPA derivation of the oral CSF for hexavalent chromium and indicated many reservations with the assumptions of mode of action, and in the derivation itself. The SAB review can be accessed at http://cfpub.epa.gov/ncea/iris_drafts/recordisplay.cfm?deid=221433. Thus, the value used to develop the RSLs for hexavalent chromium has been called into question by USEPA's peer review panel. Currently there is much scientific debate about whether the mode of action of hexavalent chromium in very high concentrations in drinking water is relevant to the low concentrations most likely to be encountered in environmental situations (Proctor, et al., 2012).

Therefore, for this evaluation, total chromium is evaluated in three ways, assuming:

- The total concentration is trivalent chromium,
- The total concentration is hexavalent chromium, using the RSLs published on the USEPA RSL table (USEPA, 2012a), and
- The total concentration is hexavalent chromium, using RSLs calculated using USEPA's on-line RSL calculator (USEPA, 2012e), based on the Tier 1 dose-response values provided in the IRIS database (USEPA, 2012b) for both potential carcinogenic and noncarcinogenic endpoints.

The graphical and quantitative evaluations use the latter, alternative, RSLs and assume that the total chromium results reported by USGS are in the hexavalent form. The assumption that all chromium in CCPs is in the hexavalent form is very conservative, and in fact unrealistic. Data for the Alaska Power Plant indicate that hexavalent chromium comprises 0.25% of the total chromium concentration in the combined fly ash/bottom ash material from that facility. Chromium speciation in CCPs, and the evaluation of trivalent chromium and the published RSLs is discussed in **Section 6.5**.

Table 17 provides a comparison of RSLs for chromium that can be derived based on currently available dose-response information, and **Figure 8** provides them graphically. These levels and their derivation will be discussed in more detail in **Section 5**, and **Section 6.3.3**.

4.7 Summary

In summary, RSLs have been developed using dose-response values that address both potentially carcinogenic and noncarcinogenic endpoints. These dose-response values are derived to over-estimate, rather than under-estimate, potential health effects, and are thus conservative. It is also important to note that the uncertainties are greatest for thallium, cobalt, and hexavalent chromium.

5.0 Exposure Assessment

For the purposes of this evaluation of the USGS CCP constituent data, it has been conservatively assumed that the CCPs are present in a residential setting, in other words, all of the exposure by a resident that would come from soil is assumed to come from CCPs. The exposure scenario and exposure factors used are discussed below.

5.1 Exposure Setting

For this evaluation, exposure to constituents present in CCPs is assumed to occur in a residential setting via the pathways used by USEPA to evaluate exposure to constituents in residential soil (USEPA, 2012c):

- Incidental ingestion,
- Inhalation of particulates emitted from soil as dust, and
- Dermal contact.

In this evaluation, it is assumed that CCPs are present as a replacement for soil on a residential property. Thus by comparing the constituent concentrations in CCPs to the RSLs for residential soil, this analysis is assuming that a resident (child and adult) is exposed to constituents in CCPs on a daily basis via incidental ingestion of CCPs, inhalation of particulates emitted from CCPs as dust, and dermal contact with CCPs. The residential exposure scenario has the highest potential for exposure of all of the scenarios used by USEPA for the RSL development. Thus, this comparison is also protective of scenarios where CCPs could be present and contacted by children and adults on a less than daily basis, such as commercial settings, day care centers, schools, parks, and along transportation corridors.

5.2 Residential Receptors

Receptors are identified as people who may contact the environmental medium of interest. For a residential scenario, a residential child and a residential adult are evaluated, per USEPA guidance (USEPA, 1989).

Because of the differences in activity patterns and sensitivity to potential constituent exposures, two age groups for the resident receptor are evaluated: the child (age 0 to 6 years) and the adult resident (USEPA, 1989). The child's lower body weight, combined with a higher intake rate for soil exposures (see below) results in a higher dose per kilogram of body weight than for other age groups. This receptor is then the most sensitive to the noncarcinogenic health effects of constituents and is, therefore, the target receptor for the noncarcinogenic analysis (i.e., estimated risks for this age group will be higher than for other older child age groups or for adults). Because potential carcinogenic effects are assumed to be additive over a lifetime, it is more conservative to evaluate potentially carcinogenic effects of constituents over the assumed period of residence (that is, the duration an individual lives at one location). For evaluating potentially carcinogenic effects, exposure as both a child and an adult is included.

5.3 Exposure Equations

The purpose of the exposure assessment is to predict the magnitude and frequency of potential human exposure to constituents in environmental media evaluated in a risk assessment.

The exposure dose is defined as the amount of constituent taken into the receptor and is expressed in units of milligrams of constituent per kilogram of body weight per day (mg/kg-day). The exposure dose is estimated for each constituent via each exposure pathway by which the receptor is assumed to be exposed. Exposure dose equations combine the estimates of constituent concentration in the environmental medium of interest (e.g., soil or CCPs) with assumptions regarding the type and magnitude of a receptor's potential exposure to that medium to provide a numerical estimate of the exposure dose.

Exposure doses are defined differently for potential carcinogenic and noncarcinogenic effects. The Chronic Average Daily Dose (CADD) is used to estimate a receptor's potential intake from exposure to a constituent with noncarcinogenic effects. According to USEPA (1989), the CADD should be calculated by averaging the dose over the period of time for which the receptor is assumed to be exposed. Therefore, the averaging period is the same as the exposure duration.

For constituents with potential carcinogenic effects, however, the Lifetime Average Daily Dose (LADD) is employed to estimate potential intake from exposure to a constituent with potential carcinogenic effects. In accordance with USEPA (1989) guidance, the LADD is calculated by averaging exposure over the receptor's assumed lifetime (70 years). Therefore, the averaging period is the same as the receptor's assumed lifetime.

Exposure doses are combined with the dose-response values to estimate potential risks and hazards for each receptor.

USEPA (2012c) provides the detailed exposure equations for the calculation of the RSLs. These are provided in **Supplement B** to this report. The equations have been copied directly from the website (USEPA's RSL documentation is not provided as a separate report or in electronic format) and unfortunately do not reproduce well. However, the equations are clear on the USEPA RSL website (http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm).

5.4 Exposure Assumptions

USEPA's generic RSLs are based on "default exposure parameters and factors that represent Reasonable Maximum Exposure (RME) conditions for long-term/chronic exposures," (USEPA, 2012c) and are based on methods outlined in USEPA guidance documents. The reasonable maximum exposure is defined by USEPA (1989) as the highest exposure that is reasonably expected to occur at a site. The intent of the RME is to estimate a conservative exposure case (i.e., well above the average case) that is still within the range of possible exposures.

Supplement B provides a table, also reproduced from the USEPA RSL website, of the exposure assumptions used in the equations that are pertinent to this evaluation.

5.4.1 Residential Child

A residential child is assumed to be aged 0 to 6 years, to weigh 15 kilograms, and to incidentally ingest 200 mg of soil (or here, CCPs) 350 days per year over a 6 year period. The residential child is assumed to breathe air containing dusts suspended from soil (or here, CCPs) 24 hours per day for

350 days per year. The residential child is also assumed to dermally contact soil (or here, CCPs) on 2,800 square centimeters of body surface area (roughly the area encompassing the head, hands, forearms, lower legs, and feet) for 350 days per year. It is assumed that vegetative cover is present on half of the residential lot, and that the soil (or here, CCPs) are bare and available for suspension as dusts on half of the residential lot.

While an assumption of 350 days per year exposure frequency may be appropriate for areas in southern climates (though it does not account for days where rain may prevent or decrease contact with soil), it is likely an overestimate for northern climates where the ground surface may be frozen in the winter months. For example, Indiana and Pennsylvania both use a residential soil exposure frequency of 250 days per year, based on meteorological data (IDEM, 2012; PADEP, 2007).

5.4.2 Residential Adult

A residential adult is assumed to weigh 70 kilograms, to incidentally ingest 100 mg of soil (or here, CCPs) 350 days per year over a 24 year period, and is assumed to have a 70 year lifetime. The upper-bound period of residence is 30 years in the US; for the residential soil RSLs for potential carcinogenic effects of constituents, it is assumed that 6 of those years are spent as a 0-6 year old child, and the remaining 24 years as an adult. The residential adult is assumed to breathe air containing dusts suspended from soil (or here, CCPs) 24 hours per day for 350 days per year. The residential adult is also assumed to dermally contact soil (or here, CCPs) on 5,700 square centimeters of body surface area (roughly the area encompassing the head, hands, forearms, and lower legs) for 350 days per year. It is assumed that vegetative cover is present on half of the residential lot, and that the soil (or here, CCPs) are bare and available for suspension as dusts on half of the residential lot.

5.5 RSLs

The RSLs are shown on **Table 15**, and the RSLs from the supporting information provided by USEPA (2012a) are also shown on the table. The RSLs for noncarcinogenic effects are based on the residential child receptor's exposure, as discussed above. The RSLs for potential carcinogenic effects are based the combined residential child and adult receptors' exposure, also described above. Again, the RSLs assume daily exposure to soils, and as used here, to CCPs by ingestion, inhalation and dermal contact for a residential lifetime.

Not only do the RSL supporting tables provide the RSLs calculated based on potentially carcinogenic and noncarcinogenic effects separately, they also provide input RSLs calculated for each route of exposure: incidental ingestion, dermal contact, and inhalation. **Table 18** provides these exposure route-specific RSLs for each constituent included in this evaluation. Note that while RSLs are provided for each exposure pathway separately, the RSLs for potentially carcinogenic and noncarcinogenic effects are calculated by combining exposure via all three pathways (see the exposure equations in **Supplement B**). However, a review of the pathway specific RSLs is instructive.

Uptake via dermal exposure from metals is very low in general, and USEPA assumes that the fraction of metals dermally absorbed for many metals is negligible, or zero (USEPA, 2012a). Thus, while the dermal pathway is considered, it is not always quantitatively adding to exposure.

A review of the supporting RSLs in **Table 18** also indicates that RSLs for the inhalation route of exposure are much higher than those derived based on ingestion exposure; this indicates that the inhalation pathway is minor contributor to exposure and to the total pathway RSLs.

For some constituents, potentially carcinogenic and noncarcinogenic RSLs are available. Six of the 20 constituents are identified as potential carcinogens; only two are identified as potential carcinogens by the oral route of exposure (for which oral RSLs are provided) – arsenic and hexavalent chromium, and six are classified as potential carcinogens by the inhalation route of exposure and for which inhalation RSLs are provided – arsenic, hexavalent chromium, beryllium, cadmium, cobalt, and nickel. While the RSLs include the oral, dermal and inhalation pathways in their derivation, the final values used on the table are all driven by the oral route of exposure. Thus, with the exception of hexavalent chromium, for the constituents that have both noncancer oral dose-response values and cancer inhalation dose-response values, the RSLs are based on the noncancer oral ingestion pathway.

The RSLs are used in the evaluations provided in **Section 6**.

5.6 Exposure Point Concentrations

Exposure points are located where potential receptors may contact constituents. For this evaluation, that is assumed to be a residential yard. The concentration of constituents in the environmental medium that receptors may contact must be estimated in order to determine the magnitude of potential exposure, this is termed the exposure point concentration (EPC).

In locations where exposure potential is considered to be random, i.e., there is an equal probability of contacting soil in one area of a residential lot versus another area, the USEPA defines the EPC as the arithmetic mean concentration of a constituent (USEPA, 1989). However, because not all locations can be sampled when conducting a site investigation, there is uncertainty about the exact value for the arithmetic mean concentration. To account for this uncertainty, the EPC for a human health risk assessment is defined as the 95% upper confidence limit (UCL) on the arithmetic mean concentration, or the maximum concentration, whichever is lower (USEPA, 2002a). This is the EPC used for the reasonable maximum exposure – RME – scenario. As noted above, the intent of the RME is to estimate a conservative exposure case (i.e., well above the average case) that is still within the range of possible exposures.

USEPA's ProUCL Version 4.1.01 software (USEPA, 2011) was used to calculate UCLs for each of the CCP datasets. The ProUCL-recommended UCL (95%, 97.5%, or 99%) was used as the EPC for each constituent in each dataset. As mentioned above, the EPC is defined as the lower of the UCL or the maximum detected value. **Tables 19 through 26** provide the EPC selection for each of the CCP datasets included in this evaluation. The UCL was selected as the EPC unless otherwise noted on the tables.

6.0 Risk Characterization

Risk characterization is the process in which the dose-response information as discussed in **Section 4** is integrated with quantitative estimates of human exposure discussed in the Exposure Assessment **Section 5**. The result is a quantitative estimate of the likelihood that humans will experience any adverse health effects given the exposure assumptions made. Two general types of health risk are characterized for each potential exposure pathway considered: potential carcinogenic risk and potential noncarcinogenic hazard.

Characterization of the potential health effects of potential carcinogenic and noncarcinogenic constituents is approached in very different ways. The difference in approaches arises from the conservative assumption that substances with possible carcinogenic action proceed by a no-threshold mechanism, whereas other toxic actions may have a threshold, i.e., a dose below which few individuals would be expected to respond. Thus, under the no-threshold assumption, it is necessary to calculate a risk, but for constituents with a threshold, it is possible to simply characterize an exposure as above or below the threshold.

To provide context for the evaluations outlined below, **Section 6.1** addresses risk characterization methods for potential carcinogens, and **Section 6.1** does the same for noncarcinogens.

As noted in **Section 1**, two methods of evaluation have been conducted using the USGS datasets for CCPs from the five US power plants.

- **RSL Comparison** - In the first, simple summary statistics are calculated for each constituent in each CCP dataset, and the results are compared to human health risk-based screening levels for residential soil developed by USEPA, the RSLs (USEPA, 2012a). CCP data and RSLs are also compared to background soil data for the US compiled by EPRI (2010) from USGS sources.
- **Cumulative Screen** - In the second method, the CCP constituent data are statistically summarized using specific USEPA methods for risk assessment, and are used in a cumulative risk screening process, also based on the USEPA RSLs (USEPA, 2012a).

The RSL comparison is presented in **Section 6.3**, and the cumulative risk screening is presented in **Section 6.4**.

6.1 Risk Characterization for Potential Carcinogens

The purpose of carcinogenic risk characterization is to estimate the upper-bound likelihood, over and above the background cancer rate, that a receptor will develop cancer in his or her lifetime as a result of exposure to a constituent in environmental media. This likelihood is a function of the dose or concentration of a constituent (described in the Exposure Assessment, **Section 5**) and the dose-response values, the SFO or IUR (described in the Dose-Response Assessment, **Section 4**) for that constituent.

The potential carcinogenic risk is calculated as follows:

Risk = Exposure Dose x Dose-Response Value

The risk calculated is the Excess Lifetime Cancer Risk (ELCR), which is the likelihood of contracting cancer over and above the background cancer rate. The ELCR is compared to the USEPA target risk range of one in one million (10^{-6}) to one in ten thousand (10^{-4}). USEPA provides the following on the cancer risk range (USEPA, 1991):

> "EPA uses the general 10(-4) to 10(-6) risk range as a "target range" within which the Agency strives to manage risks as part of a Superfund cleanup. Once a decision has been made to make an action, the Agency has expressed a preference for cleanups achieving the more protective end of the range (i.e., 10(-6)), although waste management strategies achieving reductions in site risks anywhere within the risk range may be deemed acceptable by the EPA risk manager. Furthermore, the upper boundary of the risk range is not a discrete line at 1 x 10(-4), although EPA generally uses 1 x 10(-4) in making risk management decisions. A specific risk estimate around 10(-4) may be considered acceptable if justified based on site-specific conditions, including any remaining uncertainties on the nature and extent of contamination and associated risks. Therefore, in certain cases EPA may consider risk estimates slightly greater than 1 x 10(-4) to be protective." And,
>
> "Where the cumulative carcinogenic site risk to an individual based on reasonable maximum exposure for both current and future land use is less than 10-4, and the non-carcinogenic hazard quotient is less than 1, action generally is not warranted unless there are adverse environmental impacts." And,
>
> "The upper boundary of the risk range is not a discrete line at 1 x 10-4, although EPA generally uses 1 x 10-4 in making risk management decisions. A specific risk estimate around 10-4 may be considered acceptable if justified based on site-specific conditions."

By comparison, the American Cancer Society (ACS) estimates that the lifetime probability of contracting cancer in the US is 1 in 2 (5×10^{-1}) for men and 1 in 3 (3×10^{-1}) for women (ACS, 2012). Thus the regulatory risk range is many orders of magnitude below background cancer rates in the US.

The USEPA RSLs are calculated based on a target risk level of 10^{-6} for screening purposes.

6.2 Risk Characterization for Noncarcinogens

The potential for exposure to a constituent to result in adverse noncarcinogenic health effects is estimated for each receptor by comparing the exposure dose for a constituent with the noncancer dose-response value. The resulting ratio, which is unitless, is known as the Hazard Quotient (HQ) for that constituent. The HQ is calculated using the following equation for oral and dermal exposures:

$$HQ = \frac{\text{Exposure Dose}}{\text{Dose-Response Value}}$$

The target HQ is defined as an HQ of less than or equal to one (USEPA, 1989, 1991). When the HQ is less than or equal to 1, the dose-response value has not been exceeded, and no adverse noncarcinogenic effects are expected. If the HQ is greater than 1, there may be a potential for adverse noncarcinogenic health effects to occur; however, the magnitude of the HQ cannot be directly equated to a probability or effect level.

6.3 RSL Comparison

In this method, the 10^{th} – 90^{th} percentile values from each of the USGS datasets (USGS, 2011) included in this analysis are compared graphically to the USEPA RSLs for residential soils. Constituents are identified by their chemical symbol. **Figure 6** provides a list of the chemical symbols by alphabetical order by name, by alphabetical order by chemical symbol, and in the order in which they are presented on the graphs that follow.

6.3.1 RSLs

Figure 7 graphically presents the RSLs that are shown on the first column of **Table 15**. The concentration range, in mg/kg, is presented on the left. The RSLs have been rank ordered by descending concentration, and are represented by vertical green bars. Thus the RSL for strontium is the furthest to the left as it has the highest residential soil RSL at 47,000 mg/kg. The exception to this is the RSL for trivalent chromium at 120,000 mg/kg (which is off the scale of this figure); chromium is discussed in more detail below. With the exception of arsenic and hexavalent chromium, the RSLs for the constituents are based on noncancer effects.

As stated by USEPA (USEPA, 2012d) RSLs are risk-based concentrations derived from standardized equations combining exposure information assumptions with USEPA dose-response data. RSLs are considered by the Agency to be protective for humans (including sensitive groups) over a lifetime. Generally, at sites where constituent concentrations fall below RSLs, no further action or study is warranted under the Superfund program, so long as the exposure assumptions at a site match those taken into account by the RSL calculations. Constituent concentrations above an RSL would not automatically designate a site as "dirty" or trigger a response action; however, exceeding an RSL suggests that further evaluation of the potential risks by site constituents is appropriate.

Therefore, when viewing the graph, constituent concentrations that fall at or below the top of each green bar would not be expected to pose a human health risk, even under a residential scenario for a lifetime of exposure.

The uncertainties underlying the dose-response values for cobalt, thallium and chromium were discussed in **Section 4**. It is interesting to note that the RSL for thallium is the lowest of the constituents presented, especially in light of the uncertainties discussed by USEPA in their PPRTV document for thallium, and in fact their reluctance to derive a value for thallium (USEPA, 2010b). Whether or not the use of this value is appropriate in the RSL tables, it is included here in this evaluation.

6.3.2 Arsenic

The RSL for arsenic for residential soil is 0.39 mg/kg. This is well below the range of arsenic concentrations occurring naturally in background soil of 2 to 12 mg/kg (see **Table 14**). Arsenic is the only constituent in CCPs that is classified as a carcinogen by the ingestion route of exposure by USEPA on its IRIS database (chromium is discussed below). Therefore, RSLs for arsenic at each of the target risk levels within USEPA's target risk range are presented:

- 0.39 mg/kg at a one in one million, or 10^{-6} cancer risk level (lower white bar)
- 3.9 mg/kg at a one in one hundred thousand, or 10^{-5} cancer risk level (middle white bar)
- 39 mg/kg at a one in ten thousand, or 10^{-4} cancer risk level (top of the green bar)

USEPA is currently reviewing the dose-response values for arsenic. These have not yet been finalized. Thus the RSL table uses the current dose-response values for arsenic as published on IRIS (USEPA 2012b).

6.3.3 Chromium

The total chromium concentrations report by the USGS have been compared here to the alternative RSL for hexavalent chromium of 109 mg/kg, calculated using does-response data currently available on IRIS (USEPA, 2012b).

Table 17 provides the residential soil RSLs that can be calculated for chromium in both forms, trivalent and hexavalent, using available dose-response data. These are graphically shown on **Figure 8**. As noted above, the RSL for trivalent chromium is 120,000 mg/kg. USEPA's RSL for hexavalent chromium is 0.29 mg/kg, which is a concentration much below the background concentration range for total chromium in US background soils of 15 mg/kg to 100 mg/kg (see **Table 14**). The background level of hexavalent chromium in US soils is not known, and has not been studied as there was no health-based reason for developing this information. We do know that the results of testing of the Alaska Power Plant Fly Ash/Bottom Ash indicated that hexavalent chromium accounted for 0.25% of the total chromium. We do not know if this result is representative of all of the CCPs evaluated in the USGS study, however, it is very unlikely that total chromium in the USGS CCP samples is all hexavalent chromium. See the discussion in **Section 6.5**.

As discussed in **Section 4.6.3**, there are scientific uncertainties in the oral dose-response value for potential carcinogenic effects for hexavalent chromium used by USEPA in the RSL table. This value was developed by NJDP and is numerically the same as the draft value developed by USEPA. USEPA's Science Advisory Board (SAB) provided comments in July 2011 on the draft USEPA derivation of the oral CSF for hexavalent chromium and indicated many reservations with the assumptions of mode of action, and in the derivation itself. The SAB review can be accessed at http://cfpub.epa.gov/ncea/iris_drafts/recordisplay.cfm?deid=221433. Thus, the value used to develop the RSLs for hexavalent chromium has been called into question by USEPA's peer review panel.

Based on these uncertainties, the RSL for hexavalent chromium used graphically in this evaluation is one calculated using the RSL on-line calculator, and employing the dose-response values for hexavalent chromium currently available on USEPA IRIS website (USEPA, 2012b), referred to herein as the IRIS RSL. As shown on the graph and table, this is a concentration of 109 mg/kg at a one in one million, or 10^{-6} cancer risk level.

This is compared to the USEPA-derived RSLs for hexavalent chromium:

- 0.29 mg/kg at a one in one million, or 10^{-6} cancer risk level
- 2.9 mg/kg at a one in one hundred thousand, or 10^{-5} cancer risk level
- 29 mg/kg at a one in ten thousand, or 10^{-4} cancer risk level

To be conservative, the graphical presentations of the comparison of the USGS CCP data to the RSLs include the assumption that the total chromium reported by the USGS is in the hexavalent form. As discussed, this is very unlikely.

All of these issues should be kept in mind when evaluating the chromium RSL comparisons, including the fact that these are RSLs for residential soil.

6.3.4 Fly Ash Comparisons to RSLs

Figures 9 through 13 provide the comparisons of the USGS CCP data for fly ash to the USEPA RSLs for residential soil for the Alaska, Indiana, New Mexico, Ohio and Wyoming power plants, respectively. As noted, the vertical green bars represent the residential soil RSL for each constituent. The purple bars represent the 10^{th} (bottom of the bar) to the 90^{th} (top of the bar) percentile range of the specific constituent for the specific type of CCP for the specific power plant noted (from the data presented on **Tables 3 through 7**). As discussed above, concentrations below the residential soil RSL (within the green bar), no further action or study is warranted. Constituent concentrations above an RSL would not automatically trigger a response action but suggest that further evaluation of the potential risks may be appropriate.

<u>Alaska Power Plant Fly Ash/Bottom Ash</u> – As shown on **Figure 9**, 17 of the 20 constituent concentration ranges are below the RSL (i.e., within the green bar). Total chromium concentrations are above the IRIS RSL for hexavalent chromium, but well below the RSL for trivalent chromium of 120,000 mg/kg (which is not shown on the chart as the concentration is off the scale of the chart). As noted previously, hexavalent chromium is only 0.25% of the total chromium for the Alaska Power Plant fly as/bottom ash material. The cobalt concentration range and upper bound of the thallium concentration range are above their respective RSLs.

<u>Indiana Power Plant All Fly Ash</u> – As shown on **Figure 10**, 16 of the 20 constituent concentration ranges are below the RSL (i.e., within the green bar). The upper bound of the total chromium concentrations are above the IRIS RSL for hexavalent chromium, but well below the RSL for trivalent chromium of 120,000 mg/kg (which is not shown on the chart as the concentration is off the scale of the chart). The upper bound of the vanadium, thallium and cobalt concentration ranges are above their respective RSLs, and the cobalt range is above its RSL.

<u>New Mexico Power Plant Fly Ash Product</u> – As shown on **Figure 11**, 19 of the 20 constituent concentration ranges are below the RSL (i.e., within the green bar). The range of thallium concentrations is above the RSL.

<u>Ohio Power Plant Fly Ash</u> – As shown on **Figure 12**, 16 of the 20 constituent concentration ranges are below the RSL (i.e., within the green bar). The total chromium concentrations are above the IRIS RSL for hexavalent chromium, but well below the RSL for trivalent chromium of 120,000 mg/kg (which is not shown on the chart as the concentration is off the scale of the chart). The arsenic, thallium and cobalt concentration ranges are also above their respective RSLs.

<u>Wyoming Power Plant Fly Ash</u> – As shown on **Figure 13**, 19 of the 20 constituent concentration ranges are below the RSL (i.e., within the green bar). The range of cobalt concentrations is above the RSL.

Thus, of the 20 trace elements analyzed by the USGS in fly ashes at the five power plants, only five have concentrations that are above the residential soil RSLs in one or more of the datasets. These are: chromium (three power plants – assuming all chromium is in the hexavalent form), arsenic (one power plant), thallium (four power plants), vanadium (one power plant), and cobalt (four power plants).

It should also be noted that in all datasets for fly ash, the concentrations of mercury are well below the RSL.

6.3.5 Bottom Ash Comparisons to RSLs

Figures 14 through 16 provide the comparisons of the USGS CCP data for bottom ash to the USEPA RSLs for residential soil for the New Mexico, Ohio and Wyoming power plants, respectively. For the Alaska Power Plant, the fly ash and bottom ash are mixed for beneficial use and were evaluated in the previous section. Only one sample of bottom ash was available for the Indiana Power Plant, thus, it was not included in this evaluation. As noted, the vertical green bars represent the residential soil RSL for each constituent. The purple bars represent the 10th (bottom of the bar) to the 90th (top of the bar) percentile range of the specific constituent for the specific type of CCP for the specific power plant noted (from the data presented on **Tables 8 through 10**). As discussed above, concentrations below the residential soil RSL (within the green bar), no further action or study is warranted. Constituent concentrations above an RSL would not automatically trigger a response action but suggest that further evaluation of the potential risks may be appropriate.

<u>New Mexico Power Plant Bottom Ash</u> – As shown on **Figure 14**, 19 of the 20 constituent concentration ranges are below the RSL (i.e., within the green bar). The upper bound of the range of thallium concentrations is above the RSL.

<u>Ohio Power Plant Bottom Ash</u> – As shown on **Figure 15**, 18 of the 20 constituent concentration ranges are below the RSL (i.e., within the green bar). The total chromium concentrations are above the IRIS RSL for hexavalent chromium, but well below the RSL for trivalent chromium of 120,000 mg/kg (which is not shown on the chart as the concentration is off the scale of the chart). The very narrow range of cobalt concentrations is slightly above the RSL.

<u>Wyoming Power Plant Bottom Ash</u> – As shown on **Figure 16**, 18 of the 20 constituent concentration ranges are below the RSL (i.e., within the green bar). The range of cobalt concentrations is above the RSL, and the upper bound of the vanadium concentration range is above the RSL.

Thus, of the 20 trace elements analyzed by the USGS in fly ashes at the five power plants, only four have concentrations that are above the residential soil RSLs. These are: chromium (one power plant – assuming all chromium is in the hexavalent form), thallium (one power plant), vanadium (one power plant), and cobalt (two power plants).

It should also be noted that in all datasets for bottom ash, the concentrations of mercury are well below the RSL.

6.3.6 Comparisons to Background

Table 14 provides the background concentrations of many of the constituents included in the USGS CCP datasets to concentrations in US soils compiled from USGS data sources (EPRI, 2010). Data for strontium, uranium, and lithium were not available from this source.

Figures 17 through 19 provide a progression of comparisons of constituent concentrations in fly ash, background soils and the RSLs for residential soil. For this evaluation, the data for the five fly ash datasets (from **Tables 3 through 7**) were combined into one dataset. The combined data summary statistics are shown on **Table 27**.

Figure 17 shows the 10th to 90th percentile concentration range of each constituent in the combined five-state fly ash dataset (as vertical purple bars). **Figure 18** shows the same CCP concentrations compared to the 10th to 90th percentile concentration range of each constituent in background US soils (EPRI, 2010) superimposed as vertical grey bars. As shown, there is overlap between many of the concentration ranges between the fly ash dataset and the background soil dataset, though fly ash concentration ranges are generally higher. **Figure 19** shows these fly ash and background soil concentration ranges with the USEPA RSLs for residential soils (USEPA, 2012a) superimposed (as horizontal green bars).

Figures 20 through 22 provide a progression of comparisons of constituent concentrations in bottom ash, background soils and the RSLs for residential soil. For this evaluation, the data for the three bottom ash datasets (from **Tables 8 through 10**) were combined into one dataset. The combined data summary statistics are shown on **Table 28**. The progression of information in the figures is the same as discussed above for fly ash.

As shown on this figure, the background concentration ranges for chromium, cobalt and thallium are also very near their respective RSLs.

6.4 Cumulative Risk Screening

In the screening analysis conducted above, constituent concentrations were compared directly to the USEPA RSLs for residential soil, and it was noted whether concentrations were above or below the RSLs. In a cumulative risk screen, potential risks and hazards are calculated based on the relationship between the RSLs and the target risks and hazards upon which they are based. The cumulative screening approach is discussed below, followed by the results of the evaluation. This type of cumulative screening is presented in Section 5.13.1 of the USEPA's User's Guide for the RSLs (USEPA, 2012c).

6.4.1 Cumulative Risk Screening Approach

A cumulative risk screen approach has been used to evaluate the USGS CCP data. In a cumulative risk screen, potential risks and hazards are calculated based on default screening levels. USEPA RSLs for residential soil (USEPA, 2012a), presented in **Table 15**, are used in this cumulative screen. RSLs are risk-based concentrations corresponding to a potential carcinogenic risk level of 10^{-6} and a noncarcinogenic hazard quotient (HQ) of one. As discussed above, the residential soil RSLs incorporate agency default, conservative exposure assumptions for a residential scenario (assuming exposure of 350 days per year for 30 years and conservative, default exposure parameters for incidental ingestion, dermal contact, and inhalation pathways) as well as agency selected dose-response values. Thus, the potential risks and hazards estimated using the RSLs are conservative and are likely overestimates of potential risks and hazards. This method of screening ensures that one may screen out constituents with low potential risk or hazard while taking into consideration the potential for cumulative effects. Thus a cumulative risk screen can be used to calculate a total potential carcinogenic risk that can then be compared to USEPA's target risk range (USEPA, 1991). The cumulative risk screen, and can evaluate the noncancer HQs in total, and a refined analysis based on target endpoints can be conducted if needed. The methodology for the cumulative risk screen is described below.

In a cumulative risk screen, RSLs are used to estimate the potential carcinogenic risk and noncarcinogenic hazard associated with detected concentrations. The USEPA RSL table presents the lower of the potential carcinogenic and noncarcinogenic calculated values. However, the electronic version of the USEPA RSL table provides RSLs for both potential carcinogenic and noncarcinogenic effects, where both exist. **Table 15** presents the RSLs for both potential carcinogenic and noncarcinogenic effects for comparative purposes.

The EPCs, or the 95% UCL on the arithmetic mean, were used for this evaluation, as described in **Section 5.6**. These are shown in **Tables 19 through 23** for fly ash datasets and **Tables 24 through 26** for the bottom ash datasets. The calculations were made using ProUCL version 4.1 (USEPA, 2011). As noted previously, per USEPA guidance, where a 95% UCL could not be calculated or the recommended UCL exceeded the maximum detected concentration, the maximum detected concentration was used as the exposure concentration.

To perform a comprehensive cumulative risk screen, constituents are grouped into those evaluated for potential carcinogenic effects and those evaluated for potential noncarcinogenic effects. The same constituent may appear on both lists, as some constituents have USEPA dose-response values for both types of effects. The relationship between concentration and potential risk or hazard is linear, and because the RSLs incorporate exposure assumptions, dose-response values, and target risk, the equation used to estimate potential risk based on the RSL is as follows:

$$\text{Potential Risk} = \frac{\text{Concentration (mg/kg) x RSL Target Risk } (10^{-6})}{\text{RSL (mg/kg)}}$$

Potential risks are compared to the USEPA target risk range of 10^{-6} to 10^{-4} (USEPA, 1991).

The equation used to estimate the potential HQ based on the RSL is as follows:

$$\text{Potential HQ} = \frac{\text{Concentration (mg/kg) x RSL Target HQ (1)}}{\text{RSL (mg/kg)}}$$

The evaluation of constituents with noncarcinogenic effects uses a tiered approach. As an initial step, the total HI is calculated by summing the individual constituent HQs regardless of target endpoint. As noted by USEPA, “A hazard index of 1 or less is generally considered 'safe'” (USEPA, 2012c). Where the total HI is less than or equal to one, no further evaluation is necessary. Where the total HI is greater than one, the constituents are grouped by similar target endpoint, and a target endpoint-specific HI is calculated (which is the sum of the HQs). Where the target endpoint-specific HI is less than or equal to one, no further evaluation is necessary; where the target endpoint-specific HI is greater than one, further evaluation may be necessary.

Tables 29 through 33 present the cumulative screens for the fly ash datasets for the Alaska, Indiana, New Mexico, Ohio and Wyoming power plants, respectively.

The top section of each table provides the cumulative carcinogenic risk evaluation. The constituents with RSLs for potential carcinogenic effects are listed, the exposure point concentrations or EPCs (generally the 95% UCL on the arithmetic mean) are provided, followed by the corresponding RSLs based on potential carcinogenic effects. The ratio of the two values (EPC/UCL) is multiplied by the RSL target risk level of 10^{-6}, and the resulting potential carcinogenic risk is listed for each constituent. These are then summed to provide the cumulative potential carcinogenic risk.

The bottom section of each table lists the constituents for which noncancer RSLs are available. For each constituent, the exposure point concentrations or EPCs (generally the 95% UCL on the arithmetic mean) are listed, followed by the corresponding RSLs based on noncancer effects. The ratio of the two values (EPC/UCL) is multiplied by the RSL target hazard quotient, or HQ, of one and the resulting HQ is listed for each constituent. These are then summed to provide the total hazard index or HI. If the total HI is above one, then a target endpoint analysis is provided on the bottom section of the table. Separate HQs are summed for each identified target endpoint, and the target endpoint HI is listed. Risk drivers are identified for those endpoints greater than the target of 1. Consistent with USEPA guidance, the risk results are reported with one significant figure (USEPA, 1989).

Below the target endpoint section is a table row providing the risk-based evaluation for lead. Lead is evaluated by USEPA using an exposure model rather than using the RfD approach. The residential soil screening level for lead is 400 mg/kg. For the lead evaluation, it is simply noted if the environmental concentration is above or below 400 mg/kg. Also note that according to USEPA guidance, lead is evaluated using the arithmetic mean concentration, not an upper bound on the mean (USEPA, 2002b). Detailed footnotes are provided at the end of each table.

6.4.2 Cumulative Risk Screening Results for Fly Ash

Alaska Power Plant Fly Ash/Bottom Ash – As shown on **Table 29**, the total potential carcinogenic risk is within the USEPA target risk range. The intermediate total hazard index is above one, thus a target endpoint analysis was conducted. The results indicate that thallium is a potential risk driver for a residential exposure scenario, based on adverse effects on hair as the target endpoint. Please see the discussion in **Section 4.6.1** and **Section 6.5.2.1** on the uncertainties with the dose-response value for thallium. Chromium is also a potential noncancer risk driver, however, the evaluation was conducted assuming that the total chromium results were hexavalent chromium. We know from the Alaska Power Plant that hexavalent chromium makes up only 0.25% of total chromium, thus based on that information, chromium would not be a noncancer risk driver.

Indiana Power Plant All Fly Ash – As shown on **Table 30**, the total potential carcinogenic risk is within the USEPA target risk range. The intermediate total hazard index is above one, thus a target endpoint analysis was conducted. The results indicate that thallium is a potential risk driver for a residential exposure scenario, based on adverse effects on hair as the target endpoint. Please see the discussion in **Section 4.6.1** and **Section 6.5.2.1** on the uncertainties with the dose-response value for thallium. Chromium is also a potential noncancer risk driver, however, the evaluation was conducted assuming that the total chromium results were hexavalent chromium. Cobalt has also been identified as a risk driver; again, refer to the uncertainties associated with the cobalt dose-response value in **Section 4.6.2** and **Section 6.5.2.2**. An interesting result is that lithium is a risk driver under the cumulative screen, where it was not on the direct comparison to RSLs. The 90th percentile concentration for lithium is 49.5 mg/kg, which is well below the RSL of 160 mg/kg. However the 95% UCL exposure point concentration used in the cumulative risk screen is 251 mg/kg. A review of the sample-by-sample results presented in **Table C-1** of **Appendix C** is instructive. There are 13 fly ash samples for the Indiana Power Plant; 12 of them range in concentration for lithium from 21.6 mg/kg to 33.1 mg/kg. The sample result of 251 mg/kg, which is 10-fold higher than the other results, is clearly an outlier. In fact, the concentrations of all of the constituents in that sample were 10-fold higher than the other samples, with the exception of arsenic, mercury, selenium and strontium. Without a chemist's review of the raw data, it is unclear whether this sample is truly an outlier, or if there was a systematic problem with the reporting from the laboratory analyses. While this seems to be an anomaly in this case, it also points to the utility of conducting a cumulative risk screen.

New Mexico Power Plant Fly Ash Product – As shown on **Table 31**, the total potential carcinogenic risk is within the USEPA target risk range. The intermediate total hazard index is above one, thus a target endpoint analysis was conducted. The results indicate that thallium is the only potential risk driver for a residential exposure scenario, based on adverse effects on hair as the target endpoint. Please see the discussion in **Section 4.6.1** and **Section 6.5.2.1** on the uncertainties with the dose-response value for thallium.

Ohio Power Plant Fly Ash – As shown on **Table 32**, the total potential carcinogenic risk is 2 x 10^{-4}, slightly above the USEPA target risk range of 10^{-6} to 10^{-4}. It is also important to keep in mind that this is a regulatory target, and that the background cancer rate in the US is 1 in 2 (5 x 10^{-1}) for men and 1 in 3 (3 x 10^{-1}) for women (ACS, 2012). The intermediate total hazard index is above one, thus a target endpoint analysis was conducted. The results indicate that thallium is a potential risk driver for a residential exposure scenario, based on adverse effects on hair as the target endpoint. Please see the discussion in **Section 4.6.1** and **Section 6.5.2.1** on the uncertainties with the dose-response value for thallium. Arsenic is a noncancer risk-driver based on skin and vascular endpoints, and cobalt is also a noncancer risk driver; again, refer to the uncertainties associated with the cobalt dose-response value in **Section 4.6.2** and **Section 6.5.2.2**.

Wyoming Power Plant Fly Ash – As shown on **Table 33**, the total potential carcinogenic risk is within the USEPA target risk range. The intermediate total hazard index is above one, thus a target endpoint analysis was conducted. The results indicate that thallium is a potential risk driver for a residential exposure scenario, based on adverse effects on hair as the target endpoint. Please see the discussion in **Section 4.6.1** and **Section 6.5.2.1** on the uncertainties with the dose-response value for thallium. Vanadium is also identified as a risk driver for this same endpoint. Both thallium and vanadium alone have an HQ of less than one, but added together for the hair endpoint, the total HI is greater than one. Cobalt is also a noncancer risk driver; again, refer to the uncertainties associated with the cobalt dose-response value in **Section 4.6.2** and **Section 6.5.2.2**.

6.4.3 Cumulative Risk Screening Results for Bottom Ash

Tables 34 through 36 present the cumulative screens for the bottom ash datasets for the New Mexico, Ohio and Wyoming power plants, respectively.

New Mexico Power Plant Bottom Ash – As shown on **Table 34**, the total potential carcinogenic risk is within the USEPA target risk range. The intermediate total hazard index is above one, thus a target endpoint analysis was conducted. The results indicate that all target endpoint HIs are less than or equal to one.

Ohio Power Plant Bottom Ash – As shown on **Table 35**, the total potential carcinogenic risk is within the USEPA target risk range. The intermediate total hazard index is above one, thus a target endpoint analysis was conducted. Chromium is a potential noncancer risk driver, however, the evaluation was conducted assuming that the total chromium results were hexavalent chromium, which is unlikely. Cobalt has also been identified as a noncancer risk driver; again, refer to the uncertainties associated with the cobalt dose-response value in **Section 4.6.2** and **Section 6.5.2.2**.

Wyoming Power Plant Bottom Ash – As shown on **Table 36**, the total potential carcinogenic risk is within the USEPA target risk range. The intermediate total hazard index is above one, thus a target endpoint analysis was conducted. Cobalt has also been identified as the only noncancer risk driver; again, refer to the uncertainties associated with the cobalt dose-response value in **Section 4.6.2** and **Section 6.5.2.2**.

6.4.4 Fly Ash Evaluation Summary

The potential carcinogenic risk for the Alaska, Indiana, New Mexico, and Wyoming power plant fly ash datasets is within the USEPA target risk range of 1×10^{-6} to 1×10^{-4}. The potential carcinogenic risk for the Ohio power plant fly ash dataset is 2×10^{-4}, which is slightly above the target risk level of 10^{-6} to 10^{-4} due to arsenic. By comparison, the American Cancer Society (ACS) estimates that the lifetime probability of contracting cancer in the US is 1 in 2 (5 x 10^{-1}) for men and 1 in 3 (3 x 10^{-1}) for women (ACS, 2012).

Target endpoint-specific HIs were calculated for noncarcinogens in all of the power plant fly ash datasets. Potential target endpoint specific risk drivers include arsenic (for one power plant), cobalt (for three power plants), lithium (for one power plant), thallium (for all 5 power plants), chromium (evaluated as hexavalent chromium) (for two power plants), and vanadium (for one power plant).

6.4.5 Bottom Ash Evaluation Summary

The potential carcinogenic risk for all of the power plant bottom ash datasets is within the USEPA target risk range of 10^{-6} to 10^{-4}.

Target endpoint-specific HIs were calculated for noncarcinogens for all of the power plant bottom ash datasets. No target endpoint-specific risk drivers were identified for the New Mexico Power Plant bottom ash dataset. Cobalt is a potential target endpoint specific risk driver for the Ohio and Wyoming power plant bottom ash datasets, and chromium (evaluated as hexavalent chromium) is a target endpoint risk driver for the Ohio Power Plant bottom ash dataset.

6.4.6 Cumulative Risk Screening Summary

Table 37 provides a tabular summary of the cumulative risk screening results. All potential carcinogenic risks for the fly ash and bottom ash datasets are within the USEPA target risk range of 10^{-6} to 10^{-4}. The Ohio Power Plant dataset is the only exception with a potential risk of $2x10^{-4}$, for arsenic, just slightly higher than the regulatory risk target. By comparison, the American Cancer Society (ACS) estimates that the lifetime probability of contracting cancer in the US is 1 in 2 (5 x 10^{-1}) for men and 1 in 3 (3 x 10^{-1}) for women (ACS, 2012).

Potential noncancer target endpoint risk drivers are thallium (fly ash for all five power plants), chromium (evaluated as hexavalent chromium) (fly ash for two power plants, bottom ash for one power plant), lithium (fly ash for one power plant), cobalt (fly ash for three power plants, and bottom ash for two power plants), arsenic (fly ash for one power plant), and vanadium (fly ash for one power plant).

6.5 Uncertainty Assessment

The purpose of this study for ACAA is to evaluate the CCP data generated by the USGS in the context of beneficial use. Therefore, this evaluation focuses on USGS data for the CCP materials from each facility that would likely be put into beneficial use, i.e., the final CCP product from each facility. Samples collected from intermediate steps in the power plant production of CCPs are not relevant to beneficial use and, thus, to this study.

6.5.1 Exposure Assessment

This evaluation provides a worst-case approach by assuming that exposure to CCPs put into beneficial use could be at the same level and intensity as that of a resident child and adult's exposure to soils in a backyard setting. Residential soil RSLs developed by USEPA (2012a) were used in this analysis. The RSLs for residential soil are based on a conservative residential scenario assuming daily exposure to soils for 350 days per year for a 30-year residential lifetime; thus, this evaluation has assumed the same daily exposure to CCPs in a residential setting as used by the USEPA RSLs. In the majority of beneficial use settings, exposure would be far less than that assumed for the residential scenario used here. Therefore, this assumption provides for a conservative evaluation, or over-estimate, of potential risk for CCP beneficial uses.

The USGS data for CCPs are for total concentrations of each constituent. This worst-case evaluation addresses direct contact exposure pathways in a residential setting: incidental ingestion, dermal contact, and inhalation of suspended dusts. This evaluation does not address potential leaching of constituents from CCPs in these settings; the USGS report does not provide information appropriate to address this potential pathway.

Each of the datasets evaluated has between 13 and 19 sample results. Focusing an evaluation of the maximum detected concentration within a robust dataset is inappropriate, thus, summary statistics were used to describe each of the datasets. For the direct graphical comparison to the RSLs, the range of the data as defined by the 10^{th} to 90^{th} percentiles was used. At the 10^{th} percentile concentration, 10% of the sample results are below that level, and at the 90^{th} percentile concentration, 10% of the sample results are above that level. USEPA's ProUCL software (USEPA, 2011) was used to generate the percentiles; this software identifies the percentiles based on the underlying distribution of the data (e.g., normal, lognormal). For the cumulative risk screening, USEPA guidance and software for calculating an exposure point concentration as the 95% UCL on the arithmetic mean were used (USEPA, 2011). The use of upper-bound concentrations for both methods of analysis results in a conservative evaluation that is consistent with USEPA guidance (USEPA, 1989), and that is meant to over-estimate rather than to under-estimate potential risks.

6.5.2 Dose-Response Assessment

The USEPA RSLs use dose-response information from USEPA sources. However, there are inherent uncertainties in these values based on their method of development. Uncertainties in several of these values are important to note here as the constituents have been identified as potential risk drivers for the evaluation of this assumed residential exposure setting.

6.5.2.1 Thallium

According to USEPA (2010b), a reference dose for thallium was not derived because the available toxicity database contains studies that are generally of poor quality. Appendix A of USEPA (2010b) indicates that it is inappropriate to derive provisional chronic or subchronic RfDs for thallium, but that information is available which, although insufficient to support derivation of a provisional toxicity value, under current guidelines, may be of limited use to risk assessors. It is this supplemental provisional dose-response value that has been used to develop the RSLs for thallium.

ATSDR (1992) identifies that the general population is exposed most frequently by ingestion of thallium-containing foods, especially home-grown fruits and green vegetables. It is estimated that a 70 kg adult ingests 0.005 mg thallium per day in the diet. This is equivalent to a daily dose of 7E-05 mg/kg-day (0.00007 mg/kg-day). The USEPA supplemental provisional oral reference dose for thallium is 1E-05 mg/kg-day (0.00001 mg/kg-day). This is seven times lower than the estimated dietary intake. In other words, use of this dose-response value to evaluate natural dietary exposure to thallium would indicate a hazard that is unlikely to exist.

A summary of the target endpoint specific hazard indices for thallium that are greater than the target of one are presented on **Table 37**. As shown, these range from two to 10. At a hazard index of 10, the assumed exposure to thallium via CCPs in a residential setting is less than 1.5 times the exposure from the diet; the remaining hazard indices are associated with exposures from CCPs that are below dietary levels.

This comparison, and USEPA's own discussion, illustrates the high uncertainty associated with the dose-response value for thallium, and with the resulting RSL for residential soil. This context is important, and indicates that the predicted risks for thallium in this residential evaluation are unlikely to indicate a true health risk.

6.5.2.2 Cobalt

WHO indicates that "there are no suitable data with which to derive a tolerable intake for chronic ingestion of cobalt" (WHO, 2006). ATSDR (2004) states that "adequate chronic studies of the oral toxicity of cobalt or cobalt compounds in humans and animals are not presently available." However, using a short-term study in six human volunteers, ATSDR (2004) derived an intermediate-term (15–364 days) minimal risk level of 0.05 mg/kg-day. The "adverse" effect was identified as increased red blood cell count, although it is also noted that cobalt is used as a treatment for anemia (low red blood cell count). ATSDR also notes that "Since cobalt is naturally found in the environment, people cannot avoid being exposed to it. However, the relatively low concentrations present do not warrant any immediate steps to reduce exposure." WHO notes that the largest source of exposure to cobalt for the general population is the food supply; the estimated intake from food is 5–40 ug/day, most of which is inorganic cobalt (WHO, 2006). Expressed on a mg/kg-day basis, this is 0.00007–0.0005 mg/kg-day from the diet.

USEPA, however, has derived a PPRTV for cobalt of 0.0003 mg/kg-day, this is two orders of magnitude lower than the ATSDR intermediate term MRL, and is higher that most dietary intake estimates. In other words, use of this dose-response value to evaluate natural dietary exposure to cobalt would indicate a hazard that is unlikely to exist.

A summary of the target endpoint specific hazard indices for cobalt that are greater than the target of one are presented on **Table 37**. As shown, there are four results at a hazard index of 2, and one result at a hazard index of 5. At a hazard index of 5, the assumed exposure to cobalt via CCPs in a residential setting is only twice the estimated exposure from the diet.

This comparison illustrates the high uncertainty associated with the dose-response value for cobalt, and with the resulting RSL for residential soil. This context is important, and indicates that the predicted risks for cobalt in this residential evaluation are unlikely to indicate a true health risk.

6.5.2.3 Chromium

For this evaluation, both graphically and for the cumulative risk screens, it is conservatively assumed that the total chromium reported by USGS for each dataset is present as hexavalent chromium. Chromium is generally present in two oxidation states, as trivalent chromium which is essentially nontoxic, and as hexavalent chromium. Hexavalent chromium has been regulated as a human carcinogen by the inhalation route of exposure (USEPA, 2012b).

Recent studies have shown that when present in high concentrations in drinking water, hexavalent chromium can cause gastrointestinal tract tumors in mice (NTP, 2008). As noted in **Section 4.6.3**, IRIS, which is USEPA's primary or Tier 1 database for verified dose-response information, does not present an oral CSF for hexavalent chromium; a value developed by NJDEP (2009) was used in the development of the RSLs. USEPA developed a draft oral cancer dose-response value for hexavalent chromium, based on the same study and was the same as the NJDEP value. However, it should be noted that USEPA's Science Advisory Board (SAB) provided comments in July 2011 on the draft USEPA derivation of the oral CSF for hexavalent chromium and indicated many reservations with the assumptions of mode of action, and in the derivation itself. The SAB review can be accessed at http://cfpub.epa.gov/ncea/iris_drafts/recordisplay.cfm?deid=221433. Thus, the value used to develop the RSLs for hexavalent chromium has been called into question by USEPA's peer review panel. Currently there is much scientific debate about whether the mode of action of hexavalent chromium in very high concentrations in drinking water is relevant to the low concentrations most likely to be encountered in environmental situations (Proctor, et al., 2012).

Because of this regulatory and scientific uncertainty, the RSLs used quantitatively in this evaluation for hexavalent chromium were calculated using the USEPA on-line RSL calculator (USEPA, 2012e), and the dose-response values available on IRIS. However, **Table 17** provides the range of RSLs for chromium developed using the available dose-response values and **Figure 8** depicts them graphically. The results of the cumulative risk screening shown in **Table 37** indicate that hexavalent chromium is not a driver for potential carcinogenic risks. It is identified as a potential noncancer target endpoint risk driver for the residential exposure scenario for three of the CCPs evaluated.

As noted previously, the assumption that all chromium is present in the hexavalent form is conservative and will lead to an overestimation of risks. Data for the Alaska Power Plant indicate that hexavalent chromium comprises 0.25% of the total chromium concentration in the combined fly ash/bottom ash material from that facility. Literature data for analyses of CCPs from US coals (total CCPs) indicate that hexavalent chromium can comprise up to 5% of the total chromium (Huggins, et al., 1999); thus over 95% of the total chromium is present in the nontoxic trivalent form. This is consistent with data from USEPA, though there are some single higher results (USEPA, 2009). **Table 38** presents the total chromium data for each of the CCP datasets evaluated. Assuming that hexavalent chromium could be present at up to 5% of total chromium, calculated hexavalent chromium concentrations are presented on the table. As shown, these concentrations are below the range of all of the RSLs presented for noncancer and potentially carcinogenic endpoints at the 10^{-4} risk level shown on **Table 17**. Thus, even using the current RSL for hexavalent chromium for residential soil would not result in the identification of hexavalent chromium as a risk driver.

6.5.3 Risk Characterization

The purpose of this study for ACAA is to evaluate the CCP data generated by the USGS in the context of beneficial use.

The potential cancer risk results presented on **Table 37** from the cumulative risk screen, and those that would be calculated using the refined hexavalent chromium analysis above, are all within the USEPA target risk range of 10^{-6} to 10^{-4}, with the exception of arsenic for the Ohio Power Plant fly ash dataset. It should be noted that the arsenic concentration range for the EPRI CCP dataset (EPRI, 2010) is higher than the results reported here by USGS. The 90th percentile arsenic concentration for the USGS fly ash datasets evaluated here is 58 mg/kg (see **Table 11**). The 90th percentile for the EPRI dataset is 261 mg/kg; without access to the full dataset, it is not possible to fully understand the factors that contribute to this result. Thus in some cases, the risk results, again for an assumed residential daily exposure scenario, would be above the 10^{-4} risk level for some of the CCPs represented in the EPRI dataset. However, even at an arsenic concentration of 261 mg/kg, the estimated risk for arsenic in a residential daily exposure scenario would be 7×10^{-4}.

By comparison, the American Cancer Society (ACS) estimates that the lifetime probability of contracting cancer in the US is 1 in 2 (5×10^{-1}) for men and 1 in 3 (3×10^{-1}) for women (ACS, 2012). Thus the regulatory risk range is many orders of magnitude below background cancer rates in the US.

Potential noncancer target endpoint risk drivers are thallium (fly ash for all five power plants), chromium (evaluated as hexavalent chromium) (fly ash for two power plants, bottom ash for one power plant), lithium (fly ash for one power plant), cobalt (fly ash for three power plants, and bottom ash for two power plants), arsenic (fly ash for one power plant), and vanadium (fly ash for one power plant). The previous sections have provided a detailed discussion of the uncertainties in the dose response values for thallium, cobalt and chromium.

This evaluation provides a worst-case approach by assuming that exposure to CCPs put into beneficial use could be at the same level and intensity as that of a resident child and adult's exposure to soils in a backyard setting. Residential soil RSLs developed by USEPA (2012a) were used in this analysis. The RSLs for residential soil are based on a conservative residential scenario assuming daily exposure to soils for 350 days per year for a 30-year residential lifetime; thus, this evaluation has assumed the same daily exposure to CCPs in a residential setting as used by the USEPA RSLs. In the majority of beneficial use settings, exposure would be far less than that assumed for the residential scenario used here. Therefore, this assumption provides for a conservative evaluation, or over-estimate, of potential risk for CCP beneficial uses.

7.0 Conclusion

The purpose of this study for ACAA is to evaluate the CCP data generated by the USGS (2011) from five power plants across the US each using a different source of coal, in the context of beneficial use. Therefore, this evaluation focuses on USGS data for the CCP materials from each facility that would likely be put into beneficial use, i.e., the final CCP product from each facility.

This evaluation takes a worst-case approach by assuming that exposure to CCPs put into beneficial use could be at the same level and intensity as that of a resident child and adult's exposure to soils in a backyard setting. In the majority of beneficial use settings, exposure would be far less than that assumed for the residential scenario used here. Therefore, this assumption provides for a conservative evaluation of potential risk for CCP beneficial uses.

ACAA has undertaken this evaluation to help inform the public, regulators, legislators, and the ENGOs on the potential for health risks associated with the beneficial use of CCPs. If the reports in the popular press are to be believed, the results of this analysis should have identified many instances if not the majority of CCP concentrations above very conservative risk-based screening levels for a residential daily soil exposure scenario. This is not the case. For each dataset, only two to four constituents were identified as potential risk drivers for each CCP dataset, and of these, there are uncertainties as to the appropriateness of the dose-response values for several of the constituents. The results for the two types of data analysis employed here are summarized below.

7.1 RSL Comparison

In the RSL comparison evaluation, simple summary statistics (10^{th} to 90^{th} percentiles) are calculated for each constituent in each CCP dataset, and the results are compared to human health risk-based screening levels for residential soil developed by USEPA, the Regional Screening Levels, or RSLs (USEPA, 2012a). The RSLs combine default residential assumptions for exposure and chemical-specific dose-response values to develop screening levels for soil that are protective of residential land use. The RSLs are calculated assuming daily exposure to constituents in soils in a residential setting and include incidental ingestion, dermal contact, and inhalation of airborne dusts. Thus, if CCP constituent concentrations are lower than the RSLs, there is no potential for adverse health effects or risk. In addition, CCP data are also compared to background soil data for the US compiled by EPRI (2010) from USGS sources.

7.1.1 Fly Ash Evaluation Summary

The potential carcinogenic risk for the Alaska, Indiana, New Mexico, and Wyoming power plant fly ash datasets is within the USEPA target risk range of $1\text{x}10^{-6}$ to $1\text{x}10^{-4}$. The potential carcinogenic risk for the Ohio power plant fly ash dataset is $2\text{x}10^{-4}$, which is slightly above the target risk level of 10^{-6} to 10^{-4} due to arsenic. By comparison, the American Cancer Society (ACS) estimates that the lifetime probability of contracting cancer in the US is 1 in 2 (5×10^{-1}) for men and 1 in 3 (3×10^{-1}) for women (ACS, 2012). Thus the regulatory risk range is many orders of magnitude below background cancer rates in the US.

Target endpoint-specific HIs were calculated for noncarcinogens in all of the power plant fly ash datasets. Potential target endpoint specific risk drivers include arsenic (for one power plant), cobalt (for three power plants), lithium (for one power plant), thallium (for all 5 power plants), chromium (evaluated as hexavalent chromium) (for two power plants), and vanadium (for one power plant).

7.1.2 Bottom Ash Evaluation Summary

The potential carcinogenic risk for all of the power plant bottom ash datasets is within the USEPA target risk range of 10^{-6} to 10^{-4}.

Target endpoint-specific HIs were calculated for noncarcinogens for all of the power plant bottom ash datasets. No target endpoint-specific risk drivers were identified for the New Mexico Power Plant. Cobalt is a potential target endpoint specific risk driver for the Ohio and Wyoming power plant bottom ash datasets, and chromium (evaluated as hexavalent chromium) is a target endpoint risk driver for the Ohio Power Plant bottom ash dataset.

7.2 Cumulative Risk Screening Summary

In the cumulative risk screening method, the CCP constituent data are statistically summarized using specific USEPA methods for risk assessment to calculate a 95% UCL on the arithmetic mean concentration, which is used in a cumulative risk screening process, also based on the USEPA RSLs (USEPA, 2012a), and on USEPA guidance (USEPA, 2012c).

Table 37 provides a tabular summary of the cumulative risk screening results. Potential noncancer target endpoint risk drivers are thallium (fly ash for all five power plants), chromium (evaluated as hexavalent chromium) (fly ash for two power plants, bottom ash for one power plant), lithium (fly ash for one power plant), cobalt (fly ash for three power plants, and bottom ash for two power plants), arsenic (fly ash for one power plant), and vanadium (fly ash for one power plant). **Sections 4.6 and 6.5.2** provides a detailed discussion of the uncertainties in the dose-response values for thallium, cobalt and chromium.

The dose-response values for thallium and cobalt are both provisional and other US and world regulatory bodies have stated that deficiencies in the database for these constituents precludes the development of dose-response values. The resulting uncertainties in the USEPA provisional values have resulted in dose-response values that are below the estimated daily dietary intake of both thallium and cobalt in the US.

The total chromium results reported by the USGS have been conservatively evaluated here as hexavalent chromium; trivalent chromium is essentially nontoxic, and as data indicated that trivalent chromium may make up more than 95% of the total chromium (Huggins, et al., 1999), evaluating total chromium as hexavalent chromium has been a very conservative assumption.

All potential carcinogenic risks for the fly ash and bottom ash datasets are within the USEPA target risk range of 10^{-6} to 10^{-4}. The Ohio Power Plant dataset is the only exception with a potential risk of $2x10^{-4}$, for arsenic, just slightly higher than the regulatory risk target, and well below the background cancer rate in the US of 1 in 2 (5×10^{-1}) for men and 1 in 3 (3×10^{-1}) for women (ACS, 2012).

Figure 23 shows this relationship graphically in the context of a risk arrow. High levels of risk (e.g., 1 in 2, 1 in 10) are on the left, and range to low levels of risk (e.g., 1 in one million) towards the right. The USEPA target risk range represents the excess lifetime risk of contracting cancer over and above background (USEPA, 1989). These values, as calculated using the tools of risk assessment, are hypothetical risks, and as described above, every step of the risk assessment process is designed to result in an over-estimate, not under-estimate, of risk. The USEPA target risk range is shown below the risk arrow. Above the risk arrow are depicted the risks of fatality in the US from various events – these are risks based on measurements of incidence in the US population. Also shown on the arrow is the background cancer rate in the US, to the far left on the risk arrow.

Thus the risks calculated here for a hypothetical exposure scenario where the soil in a residential yard is replaced with CCPs are well below background cancer risks in the US, and below background risks of fatality from a number of common events.

A refined analysis of the chromium data, including evaluating the range of dose-response values available for hexavalent chromium from USEPA sources, indicates that had the USGS conducted chromium speciation analyses for the CCPs, hexavalent chromium would likely not be identified as a potential cancer or noncancer risk driver.

7.3 Summary

In summary, all of the constituents present in CCPs are also present in the background soils in the US – soils in our yards, in our parks and at our schools. By virtue of this fact, people are naturally exposed to these constituents on a daily basis through incidental soil ingestion, through inhalation of dusts blown from soils, and most importantly, through the foods we eat. Plants grow in soil, and take up these constituents as they grow; thus, these constituents enter our food chain. Several of the constituents evaluated here, including selenium, manganese, molybdenum, nickel, zinc, copper, chromium, vanadium, boron and tin, are also present in our daily vitamins.

While concentrations of these trace elements are similar to background soils, in some instances the concentration ranges are above background. To address these differences, this risk-based evaluation assumes that a residential child and adult are exposed to the constituents present in CCPs on a daily basis, in essence, that the soil in a residential yard is completely replace by CCPs. The results demonstrate that with few exceptions constituent concentrations in CCPs are below screening levels for residential soils, and are similar in concentration to background US soils. Thus, coal ash does not qualify as a hazardous substance based on its composition, and it also should not be classified as hazardous on a human health risk basis.

Most importantly, because exposure to constituents in coal ash used in beneficial applications, such as concrete, road base, or structural fill would be much lower than assumed for a residential scenario, these uses should also not pose a direct contact risk to human health.

8.0 References

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Tables

Table 1
Selection of USGS CCP Datasets for Risk-Based Evaluation
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Power Plant Location	Coal Used	Coal Ash Data Available from (a)	Material Selected for Risk-Based Evaluation (b)	Rationale
Alaska	Nenana Coal Province	Fly Ash Hopper		Information obtained from the Alaska Power Plant indicates that the coal ash from the silo (combined fly ash/bottom as) is the material put into beneficial use (b).
		Fly Ash Before Last Ash Hopper		
		Fly Ash After Boiler		
		Bottom Ash		
		Fly Ash Silo (Includes both Fly Ash and Bottom Ash)	X	
Indiana	Illinois	Bottom Ash	(c)	From the Indiana Power Plant schematic (b), it was concluded that the economizer fly ash and air preheater ash represent intermediate steps in fly ash production. It is assumed that the bottom ash and fly ash represent materials that could be benefically used.
		Economizer Fly Ash		
		Fly Ash	X	
		Air Preheater Ash		
		Gypsum	(c)	
		Sludge	(c)	
New Mexico	San Juan	Bottom Ash	X	From the New Mexico Power Plant schematic (b), it was concluded that the fly ash north and fly ash south materials represent intermediate steps in fly ash production. It is assumed that the material labeled fly ash (product) and bottom ash represent materials that could be benefically used.
		Fly Ash North		
		Fly Ash South		
		Fly Ash Coarse		
		Fly Ash (Product)	X	
Ohio	Appalachian	Bottom Ash	X	From the Ohio Power Plant schematic (b), it was concluded that the economizer fly ash represents an intermediate step in fly ash production. It is assumed that the bottom ash and fly ash represent materials that could be beneficially used.
		Economizer Fly Ash		
		Fly Ash	X	
Wyoming	Powder River	Bottom Ash	X	From the Wyoming Power Plant schematic (b), it was concluded that the economizer fly ash represents an intermediate step in fly ash production. It is assumed that the bottom ash and fly ash represent materials that could be beneficially used.
		Economizer Fly Ash		
		Fly Ash	X	

Notes:
(a) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635.
Available at: http://pubs.usgs.gov/ds/635/
(b) - Power plant schematics and coal ash sample collection locations are provided in Appendix A.
(c) - There is only one sample result for this material from the Indiana Power Plant, so the material was not included in the evaluation.

Table 2
Sample Summary (a)
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Power Plant Location	Coal Used	Coal Ash Included in Risk-Based Evaluation	Sample Size
Alaska	Nenana Coal Province	Fly Ash/Bottom Ash	19
Indiana	Illinois	Fly Ash	13
New Mexico	San Juan	Fly Ash (Product)	16
		Bottom Ash	18
Ohio	Appalachian	Fly Ash	13 (b)
		Bottom Ash	15
Wyoming	Powder River	Fly Ash	15
		Bottom Ash	15

Notes:
(a) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(b) - Although the USGS report Table 2 lists 14 samples for Fly Ash from the Ohio Power Plant, the supporting materials provide data for 13 samples.

Table 3
Summary Statistics - Alaska Power Plant Fly Ash/Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Alaska Power Plant Summary Statistics for Fly Ash/Bottom Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	19:19	4.21	12.1	7.305	7.12	4.542	7.12	10.72
Arsenic	19:19	7.3	32.9	18.77	14.9	10.66	14.9	29.22
Barium	19:19	4290	5730	4959	4740	4516	4740	5514
Beryllium	19:19	1.69	3.16	2.338	2.29	1.83	2.29	2.886
Cadmium	19:19	0.38	1.84	0.955	0.992	0.451	0.992	1.492
Chromium	19:19	247	925	407.5	322	273.2	322	754.2
Cobalt	19:19	24.6	32.6	28.78	28.7	25.46	28.7	31.5
Copper	19:19	114	197	153	147	127.6	147	180.8
Lead	19:19	14.4	77	39.08	27.9	18.26	27.9	66.06
Lithium	19:19	13.2	30.4	22.96	24.5	16.3	24.5	29.04
Manganese	19:19	731	966	873	898	784.8	898	947.2
Mercury	19:19	0.123	1.15	0.462	0.329	0.179	0.329	0.979
Molybdenum	19:19	19.6	45.4	34.35	33.4	27.42	33.4	43.2
Nickel	19:19	159	280	226.8	226	186.2	226	266.6
Selenium	19:19	1.25	7.14	3.291	2.47	1.744	2.47	5.968
Strontium	19:19	1240	1830	1479	1340	1248	1340	1760
Thallium	19:19	0.312	1.99	0.725	0.582	0.314	0.582	1.158
Uranium	19:19	0.682	1.1	0.916	0.853	0.783	0.853	1.082
Vanadium	19:19	203	418	265.5	236	229.4	236	370.2
Zinc	19:19	33.1	233	76.12	53.5	41.5	53.5	119.8

Notes:

FOD - Frequency of Detection - Number of detected results: Total number of samples.

(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011).

(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

Table 4
Summary Statistics - Indiana Power Plant Fly Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Indiana Power Plant Summary Statistics for Fly Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	13:13	1.96	22.4	4.115	2.38	2.086	2.38	4.322
Arsenic	13:13	20.2	56.3	26.13	24	22.12	24	25.28
Barium	13:13	336	422	379.5	375	352	375	416.4
Beryllium	13:13	2.32	32.7	5.328	2.75	2.592	2.75	5.078
Cadmium	13:13	0.79	3.29	1.152	0.981	0.814	0.981	1.35
Chromium	13:13	78.2	984	169.1	96.7	87.56	96.7	143.6
Cobalt	13:13	22.5	264	45.31	26.7	24.54	26.7	34.6
Copper	13:13	156	692	223.8	175	167.6	175	233
Lead	13:13	22.1	293	50.15	30.7	24.9	30.7	42.46
Lithium	13:13	21.6	560	68.38	24.8	21.86	24.8	49.5
Manganese	13:13	105	723	200.8	161	137.4	161	195.6
Mercury	13:13	0.0127	0.104	0.0376	0.0264	0.0206	0.0264	0.0631
Molybdenum	13:13	5.32	90.5	13.74	6.44	5.836	6.44	15.88
Nickel	13:13	58.2	572	107.9	67.5	62.06	67.5	91.04
Selenium	13:13	4.06	22.5	8.622	6.49	4.932	6.49	13.48
Strontium	13:13	319	638	418.7	379	323	379	594
Thallium	13:13	0.382	21	2.133	0.485	0.438	0.485	1.175
Uranium	13:13	5.33	34.1	8.666	6.45	6.058	6.45	8.216
Vanadium	13:13	262	1660	419.6	317	267.8	317	420
Zinc	13:13	122	848	238.2	183	148.2	183	293

Notes:
FOD - Frequency of Detection - Number of detected results: Total number of samples.
(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011).
(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

Table 5
Summary Statistics - New Mexico Power Plant Fly Ash Product
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

New Mexico Power Plant Summary Statistics for Fly Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	16:16	2.79	3.78	3.266	3.14	2.98	3.14	3.705
Arsenic	16:16	16.8	22.2	19.58	19.1	18.3	19.1	21.75
Barium	16:16	1230	1950	1664	1655	1500	1655	1890
Beryllium	16:16	5.06	6.69	5.745	5.66	5.2	5.66	6.345
Cadmium	16:16	0.42	0.68	0.528	0.509	0.435	0.509	0.628
Chromium	16:16	33.7	45.9	37.68	36.1	34.2	36.1	42.5
Cobalt	16:16	14.5	18.3	15.84	15.35	14.8	15.35	17.5
Copper	16:16	60.8	68.7	65.01	65.05	62.1	65.05	67.95
Lead	16:16	53.8	67.5	61.88	62.55	56.95	62.55	66.9
Lithium	16:16	91.8	116	101.9	102	94.95	102	108.5
Manganese	16:16	180	222	197.5	193.5	189	193.5	209.5
Mercury	16:16	0.0648	0.263	0.138	0.119	0.0685	0.119	0.233
Molybdenum	16:16	7.94	9.35	8.632	8.59	8.055	8.59	9.21
Nickel	16:16	17.3	22.9	19.88	20	18.2	20	21.75
Selenium	16:16	1.03	12.2	8.39	8.67	5.89	8.67	11.3
Strontium	16:16	345	476	402.1	396	377.5	396	433
Thallium	16:16	1.07	2.9	1.548	1.33	1.14	1.33	1.87
Uranium	16:16	12	13.5	12.7	12.7	12.25	12.7	13.25
Vanadium	16:16	106	128	113.9	111.5	108.5	111.5	121
Zinc	16:16	70.4	83.5	77.67	78.85	71.85	78.85	82.05

Notes:
FOD - Frequency of Detection - Number of detected results: Total number of samples.
(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011).
(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

Table 6
Summary Statistics - Ohio Power Plant Fly Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Ohio Power Plant Summary Statistics for Fly Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	13:13	0.982	5.3	2.051	1.95	1.39	1.95	2.186
Arsenic	13:13	33.7	93.8	59.04	60.3	40.48	60.3	67.36
Barium	13:13	464	608	530.2	518	476.6	518	599
Beryllium	13:13	8.03	15.4	11.26	11.7	8.91	11.7	13.56
Cadmium	13:13	0.312	0.963	0.736	0.789	0.6	0.789	0.872
Chromium	13:13	118	181	147.8	133	122.4	133	180.2
Cobalt	13:13	27.6	46.4	36.09	32.6	28.56	32.6	44.16
Copper	13:13	55.1	193	85.22	77.8	60.74	77.8	101.3
Lead	13:13	21.4	50.4	39.07	41.8	33.2	41.8	44.26
Lithium	13:13	74	140	110	97.9	90.98	97.9	136.8
Manganese	13:13	193	333	252.8	236	196.4	236	327.4
Mercury	13:13	0.0167	0.0561	0.0322	0.0318	0.0212	0.0318	0.0437
Molybdenum	13:13	7.15	18.4	10.47	10.6	8.314	10.6	11.06
Nickel	13:13	79.5	123	97.95	102	83.1	102	113.8
Selenium	13:13	3.49	5.47	4.125	4.11	3.662	4.11	4.74
Strontium	13:13	587	763	666.6	648	616.8	648	723.4
Thallium	13:13	1.06	6.13	3.434	3.37	2.514	3.37	4.116
Uranium	13:13	5.2	9.58	7.663	7.3	6.004	7.3	9.342
Vanadium	13:13	179	317	248	229	192.2	229	304.6
Zinc	13:13	62.7	141	111	111	95.36	111	135

Notes:

FOD - Frequency of Detection - Number of detected results: Total number of samples.

(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011).

(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

Table 7

Summary Statistics - Wyoming Power Plant Fly Ash

Coal Ash Material Safety - A Health Risk-Based Evaluation

American Coal Ash Association

Wyoming Power Plant Summary Statistics for Fly Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	15:15	1.65	2.11	1.917	1.91	1.67	1.91	2.088
Arsenic	15:15	14.6	22	19.41	20	17.22	20	20.9
Barium	15:15	2980	3370	3174	3170	3110	3170	3256
Beryllium	15:15	2.07	3.1	2.706	2.74	2.456	2.74	2.876
Cadmium	15:15	0.699	0.895	0.804	0.814	0.74	0.814	0.89
Chromium	15:15	54.1	102	83.64	82.4	77.6	82.4	93.28
Cobalt	15:15	31.4	43.5	38.72	39.4	36	39.4	42.26
Copper	15:15	118	171	148.9	144	138.4	144	166
Lead	15:15	25	33.1	28.37	28.2	26.22	28.2	30.46
Lithium	15:15	21.8	32.9	29.17	29	27.4	29	32.2
Manganese	15:15	145	283	214.9	229	156.6	229	254.4
Mercury	15:15	0.0212	0.971	0.604	0.695	0.0719	0.695	0.947
Molybdenum	15:15	4.95	6.09	5.689	5.78	5.364	5.78	5.966
Nickel	15:15	106	180	157.6	158	148.4	158	170.6
Selenium	15:15	11.2	13.5	12.35	12.3	11.5	12.3	13.16
Strontium	15:15	2180	2400	2293	2290	2230	2290	2364
Thallium	15:15	0.472	0.747	0.594	0.593	0.517	0.593	0.668
Uranium	15:15	7.29	11.2	8.748	8.45	7.656	8.45	10.41
Vanadium	15:15	218	376	312.3	317	247.2	317	365.4
Zinc	15:15	87.9	186	135.2	136	112	136	167.4

Notes:

FOD - Frequency of Detection - Number of detected results: Total number of samples.

(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011).

(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

Table 8

Summary Statistics - New Mexico Power Plant Bottom Ash

Coal Ash Material Safety - A Health Risk-Based Evaluation

American Coal Ash Association

New Mexico Power Plant Summary Statistics for Bottom Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	18:18	0.401	0.911	0.623	0.61	0.412	0.61	0.845
Arsenic	18:18	1.24	18.1	3.046	2.175	1.464	2.175	3.076
Barium	18:18	983	2000	1415	1435	1108	1435	1726
Beryllium	18:18	3.41	5.33	4.157	4.085	3.504	4.085	4.949
Cadmium	0:18	ND	ND	ND	ND	ND	ND	ND
Chromium	18:18	17.5	30.1	22.31	20.7	18.91	20.7	27.81
Cobalt	18:18	7.29	10.6	8.582	8.41	7.331	8.41	9.967
Copper	18:18	40.4	47.5	42.87	42.5	41.5	42.5	44.77
Lead	18:18	16.5	23	19.22	19.2	17.52	19.2	21.19
Lithium	18:18	82.6	120	98.37	97.75	87.74	97.75	109
Manganese	18:18	159	308	238.1	239.5	199.8	239.5	274.5
Mercury	3:18	0.0307	0.155	0.0996	0.113	0.04716	0.113	0.1466
Molybdenum	18:18	2.15	3.64	2.709	2.705	2.278	2.705	3.181
Nickel	18:18	28.8	49.5	35.75	34.9	29.67	34.9	42.88
Selenium	16:18	0.121	0.626	0.227	0.193	0.1285	0.1925	0.327
Strontium	18:18	270	408	328.9	339	277.8	339	366.4
Thallium	11:18	0.115	1.96	0.73	0.59	0.144	0.59	1.57
Uranium	18:18	9.03	11	9.663	9.365	9.159	9.365	10.42
Vanadium	18:18	69.4	95.5	77.53	74.1	70.52	74.1	87.74
Zinc	18:18	26.5	53.2	32.38	31.1	27.34	31.1	35.92

Notes:

FOD - Frequency of Detection - Number of detected results: Total number of samples.

(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011). ProUCL does not calculate summary percentiles for datasets with non-detect values. Therefore, mercury, selenium and thallium percentiles calculated using Microsoft Excel for detected values only.

(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

Table 9
Summary Statistics - Ohio Power Plant Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Ohio Power Plant Summary Statistics for Bottom Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	15:15	0.867	3.2	1.289	1.02	0.881	1.02	2.016
Arsenic	15:15	3.6	12.9	5.981	5.27	3.742	5.27	9.648
Barium	15:15	474	518	491.9	491	479.4	491	501
Beryllium	15:15	7.72	10.3	9.019	8.84	8.074	8.84	10.22
Cadmium	13:15	0.104	0.169	0.125	0.125	0.1056	0.125	0.1492
Chromium	15:15	266	461	377	374	340.6	374	418.6
Cobalt	15:15	34.5	37.7	36.23	36.2	35.34	36.2	37.1
Copper	15:15	54	69.1	61.37	60.9	57.94	60.9	67.14
Lead	15:15	13.9	40	17.45	15	14.16	15	21
Lithium	15:15	86.4	98.6	92.8	92.5	89.46	92.5	97.34
Manganese	14:15	296	347	322.6	320	308.8	320	338.1
Mercury	2:15	0.0123	0.0207	0.0165	0.0165	0.01314	0.0165	0.01986
Molybdenum	15:15	6.31	10.2	8.121	8.17	6.774	8.17	9.252
Nickel	15:15	162	240	202.3	207	180.2	207	217.8
Selenium	7:15	0.129	0.755	0.271	0.187	0.1356	0.187	0.4826
Strontium	15:15	554	636	601.1	615	564.4	615	629.6
Thallium	15:15	0.446	0.684	0.554	0.55	0.498	0.55	0.606
Uranium	15:15	5.27	7.08	5.753	5.63	5.382	5.63	6.096
Vanadium	15:15	192	221	209.2	211	198	211	220.2
Zinc	15:15	55.9	72.9	61.17	61.2	57.22	61.2	63.02

Notes:
FOD - Frequency of Detection - Number of detected results: Total number of samples.
(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011). ProUCL does not calculate summary percentiles for datasets with non-detect values. Therefore, cadmium, mercury, manganese and selenium percentiles calculated using Microsoft Excel for detected values only.
(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

Table 10
Summary Statistics - Wyoming Power Plant Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Wyoming Power Plant Summary Statistics for Bottom Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	15:15	0.568	1.05	0.746	0.773	0.598	0.773	0.829
Arsenic	15:15	4.99	7.73	6.479	6.65	5.228	6.65	7.246
Barium	15:15	2440	2990	2753	2790	2526	2790	2940
Beryllium	15:15	2.99	3.78	3.365	3.37	2.998	3.37	3.704
Cadmium	14:15	0.138	0.425	0.201	0.17	0.1473	0.17	0.3304
Chromium	15:15	62.8	89.9	76.23	74.6	65.24	74.6	88.08
Cobalt	15:15	36.6	55	46.03	46.1	39.98	46.1	50.94
Copper	15:15	110	148	130.5	133	118	133	143.8
Lead	15:15	7.59	10.5	9.265	9.52	7.682	9.52	10.26
Lithium	15:15	29.5	39.3	34.85	35.4	30.84	35.4	38.68
Manganese	15:15	145	282	249.6	265	184.8	265	278.8
Mercury	10:15	0.0145	0.111	0.0373	0.0228	0.01504	0.0228	0.06294
Molybdenum	15:15	3	3.37	3.187	3.21	3.016	3.21	3.322
Nickel	15:15	65.3	255	93.91	77.3	67.58	77.3	126.2
Selenium	14:15	0.169	1.28	0.614	0.547	0.2301	0.547	1.0327
Strontium	15:15	2370	2680	2539	2560	2434	2560	2632
Thallium	15:15	0.102	0.294	0.166	0.159	0.117	0.159	0.212
Uranium	15:15	8.44	9.55	8.983	8.95	8.49	8.95	9.46
Vanadium	15:15	279	591	411.3	347	296.4	347	569.6
Zinc	15:15	51.7	152	84.93	74	53.38	74	125

Notes:
FOD - Frequency of Detection - Number of detected results: Total number of samples.
(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011). ProUCL does not calculate summary percentiles for datasets with non-detect values. Therefore, cadmium, mercury and selenium percentiles calculated using Microsoft Excel for detected values only.
(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

Table 11

Summary Statistics - Alaska, Indiana, New Mexico, Ohio and Wyoming Power Plants Fly Ash

Coal Ash Material Safety - A Health Risk-Based Evaluation

American Coal Ash Association

Five State Summary Statistics for Fly Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	76:76	0.982	22.4	3.947	2.88	1.695	2.88	8.595
Arsenic	76:76	7.3	93.8	27.21	20.95	14.55	20.95	57.95
Barium	76:76	336	5730	2372	1745	389	1745	5050
Beryllium	76:76	1.69	32.7	5.166	2.875	2.215	2.875	11.35
Cadmium	76:76	0.312	3.29	0.831	0.791	0.462	0.791	1.24
Chromium	76:76	33.7	984	180.5	100.6	36.1	100.6	360
Cobalt	76:76	14.5	264	32.1	28.65	15.35	28.65	41.25
Copper	76:76	55.1	692	134.2	139.5	64.6	139.5	186.5
Lead	76:76	14.4	293	43.66	33.8	23.65	33.8	64.85
Lithium	76:76	13.2	560	63.47	30.15	21.75	30.15	110.5
Manganese	76:76	105	966	379.8	217.5	158.5	217.5	908
Mercury	76:76	0.0127	1.15	0.276	0.128	0.0243	0.128	0.844
Molybdenum	76:76	4.95	90.5	15.67	8.705	5.755	8.705	35.25
Nickel	76:76	17.3	572	127.2	107	20	107	234.5
Selenium	76:76	1.03	22.5	7.208	6.09	2.175	6.09	12.55
Strontium	76:76	319	2400	1093	700.5	375	700.5	2290
Thallium	76:76	0.312	21	1.576	0.77	0.418	0.77	3.295
Uranium	76:76	0.682	34.1	7.422	7.37	0.848	7.37	12.7
Vanadium	76:76	106	1660	266.2	251	111.5	251	363.5
Zinc	76:76	33.1	848	121.8	106	51.55	106	184.5

Notes:

FOD - Frequency of Detection - Number of detected results: Total number of samples.

(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011).

(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

Table 12
Summary Statistics - New Mexico, Ohio and Wyoming Power Plants Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

New Mexico, Ohio and Wyoming Power Plants Summary Statistics for Bottom Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	48:48	0.401	3.2	0.869	0.797	0.488	0.797	1.15
Arsenic	48:48	1.24	18.1	5.036	4.775	1.744	4.775	7.344
Barium	48:48	474	2990	1545	1435	486.8	1435	2840
Beryllium	48:48	2.99	10.3	5.429	4.085	3.206	4.085	9.316
Cadmium	27:48	0.104	0.425	0.165	0.148	0.1132	0.148	0.2056
Chromium	48:48	17.5	461	150	72	19.47	72	397.5
Cobalt	48:48	7.29	55	28.92	36.05	7.818	36.05	49.46
Copper	48:48	40.4	148	76.03	59.8	41.81	59.8	135.6
Lead	48:48	7.59	40	15.56	15.8	8.79	15.8	20.01
Lithium	48:48	29.5	120	76.78	90.15	33.64	90.15	106
Manganese	47:48	145	347	266.9	266	214.8	266	324
Mercury	15:48	0.0123	0.155	0.047	0.0229	0.01474	0.0229	0.1122
Molybdenum	48:48	2.15	10.2	4.55	3.215	2.493	3.215	8.465
Nickel	48:48	28.8	255	106	74.45	31.29	74.45	214.6
Selenium	37:48	0.121	1.28	0.382	0.253	0.136	0.253	0.8814
Strontium	48:48	270	2680	1105	588.5	291.7	588.5	2563
Thallium	41:48	0.102	1.96	0.459	0.446	0.128	0.446	0.747
Uranium	48:48	5.27	11	8.229	9.045	5.597	9.045	9.96
Vanadium	48:48	69.4	591	223	206.5	72.65	206.5	512.1
Zinc	48:48	26.5	152	57.8	57.85	28.19	57.85	91.44

Notes:
FOD - Frequency of Detection - Number of detected results: Total number of samples.
(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011). ProUCL does not calculate summary percentiles for datasets with non-detect values. Therefore, cadmium, mercury, manganese, selenium and thallium percentiles calculated using Microsoft Excel for detected values only.
(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

Table 13
Major and Minor Element Composition of CCPs Evaluated
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

State	Alaska	Indiana	New Mexico		Ohio		Wyoming	
Material	Fly/Bottom Ash	Fly Ash	Fly Ash (Product)	Bottom Ash	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash
USGS Table No. (a)	14	18	24	20	30	28	36	34
Major and Minor Elements	Mean (Average) Percent							
SiO_2	45.3	41.1	62.8	64.8	41.7	40	29	43.3
Al_2O_3	19.3	21.5	26	24.1	18.2	17.6	15.6	20
CaO	19.9	1.46	2.62	2.95	2.32	2.32	26.3	16.3
MgO	3.37	0.79	0.821	0.735	0.631	0.594	3.34	3.81
Na_2O	0.262	0.384	1.31	1.04	1.75	0.317	0.543	0.266
K_2O	1.21	2.13	0.89	0.871	1.47	1.29	0.398	0.423
Fe_2O_3	7.72	25.7	3.57	4.36	26.9	29.9	3.32	9.75
TiO_2	0.787	1.09	0.938	0.821	0.959	0.895	1.14	1.51
P_2O_5	0.194	0.181	0.183	0.123	0.218	0.169	0.462	0.446
SO_3	1.03	0.491	0.07	0.122	2.46	0.197	19.2	0.503
Total Mean Percent	**99.073**	**94.826**	**99.202**	**99.922**	**96.608**	**93.282**	**99.303**	**96.308**
Remainder	**0.927**	**5.174**	**0.798**	**0.078**	**3.392**	**6.718**	**0.697**	**3.692**

Notes:
(a) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635.
Available at: http://pubs.usgs.gov/ds/635/

Table 14
Constituent Concentrations in US Soils (a)
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Constituent	Number of Samples	Units	Maximum	Percentile			Minimum
				90th	50th	10th	
Arsenic	1258	mg/kg	97	12	5.8	2	<0.1
Antimony	355	mg/kg	8.78	1.3	<1	<1	<1
Barium	1320	mg/kg	5000	1000	500	200	10
Beryllium	1304	mg/kg	15	2	<1	<1	<1
Cadmium	830	mg/kg	8.2	0.5	0.2	<0.1	<0.1
Chromium	1320	mg/kg	2000	100	50	15	<1
Cobalt	1324	mg/kg	70	15	7	<3	<3
Copper	1312	mg/kg	700	50	20	5	<1
Lead	1320	mg/kg	700	30	15	<10	<10
Manganese	1318	mg/kg	7000	1000	300	100	<2
Molybdenum	1299	mg/kg	15	<3	<3	<3	<3
Mercury	1268	mg/kg	4.6	0.19	0.05	0.02	<0.02
Nickel	1319	mg/kg	700	30	15	5	<3
Selenium	1268	mg/kg	4.32	0.8	0.3	<0.1	<0.1
Thallium	830	mg/kg	1.8	0.7	0.5	0.2	<0.1
Vanadium	1320	mg/kg	500	150	70	20	<7
Zinc	1249	mg/kg	2890	99	50	22	<5

Notes:
(a) - Data from EPRI, 2010. Comparison of Coal Combustion Products to Other Common Materials.
Report No. 1020556. Available for download at www.epri.com
Table 2-2: Statistical Summary of the Concentrations of Various Elements in Other Materials.

Table 15
USEPA Regional Screening Levels (RSLs) for Residential Soils
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

				Residential Soil Regional Screening Level (a) (i)					
					Carcinogenic Component		Noncarcinogenic Component		
Constituent		**CAS No**	**Units**	**RSL**	**RSL Carc.**	**Basis of Screening Level**	**RSL Noncarc.**	**Basis of Screening Level**	**Noncancer Target Endpoint Oral (j)**
Arsenic		7440-38-2	mg/kg	0.39	0.39	O/D/I	22	O/D/I	Hyperpigmentation, Kertosis and Possible Vascular Complications
Antimony	(b)	7440-36-0	mg/kg	31	NC		31	O	Longevity, blood glucose, and cholesterol
Barium		7440-39-3	mg/kg	15000	NC		15,000	O/I	Nephropathy
Beryllium		7440-41-7	mg/kg	160	1400	I	160	O/I	Small intestinal lesions
Cadmium		7440-43-9	mg/kg	70	1800	I	70	O/D/I	Significant proteinuria
Chromium-6	(c)	18540-29-9	mg/kg	0.29	0.29	I/O	230	O/I	None reported
Chromium-6	(d)	18540-29-9	mg/kg	NA	109	I	235	O/I	None reported
Chromium-3	(e)	16065-83-1	mg/kg	120000	NC		120,000	O	None reported
Cobalt		7440-48-4	mg/kg	23	370	I	23	O/I	Thyroid toxicity
Copper		7440-50-8	mg/kg	3100	NC		3,100	O	Gastrointestinal irritation
Lead		7439-92-1	mg/kg	400	NC		400	O	(h)
Lithium		7439-93-2	mg/kg	160	NC		160	O	Adverse renal effects
Manganese	(f)	7439-96-5	mg/kg	1800	NC		1,800	O/I	CNS Effects (Other Effect: Impairment of Neurobehavioral Function)
Mercury	(g)	7487-94-7	mg/kg	23	NC		23	O/I	Autoimmune effects
Molybdenum		7439-98-7	mg/kg	390	NC		390	O	Increased uric acid levels (kidney effects)
Nickel		7440-02-0	mg/kg	1500	13000	I	1,500	O/I	Decreased body and organ weights
Selenium		7782-49-2	mg/kg	390	NC		390	O/I	Clinical Selenosis (Skin, Nails, Hair, Behavioral)
Strontium		7440-24-6	mg/kg	47000	NC		47,000	O	Rachic bone
Thallium		7440-28-0	mg/kg	1	NC		0.78	O	Hair follicle atrophy
Uranium		NA	mg/kg	230	NC		230	O/I	Initial body weight loss; moderate nephrotoxicity
Vanadium		NA	mg/kg	390	NC		390	O	Decreased hair cystine
Zinc		7440-66-6	mg/kg	23000	NC		23,000	O	Decreases in erythrocyte Cu, Zn-superoxide dismutase (ESOD) activity

Notes:
CAS - Chemical Abstracts Service.
D - Screening level includes the dermal pathway.
I - Screening level includes the inhalation pathway.
NA - Not Available.
NC - Not Calculated; not a potential carcinogen.
O - Screening level includes the oral pathway.
RSL - Regional Screening Level.
USEPA - US Environmental Protection Agency.
(a) - USEPA, 2012. Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012. Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm.
(b) - RSLs for metallic antimony.
(c) - RSLs for hexavalent chromium. Based on toxcity data not presented in the Integrated Risk Information System.
(d) - Alternative screening level calculated for hexavalent chromium using RSL calculator and current dose-response data from the Integrated Risk Information System. Available at: http://www.epa.gov/IRIS/
(e) - RSLs for trivalent chromium.
(f) - RSLs for manganese (non-diet).
(g) - RSLs for mercuric chloride.
(h) - Lead is not included in the calculation of target-endpoint specific hazard quotients.
(i) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.
(j) - Where the RSL is based on multiple pathways, the oral pathway is the driver. Therefore, target endpoints are based on the oral pathway.

Table 16
Dose-Response Values Used for Regional Screening Levels (RSLs)
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

			Residential Soil Regional Screening Level (RSL) Dose-Response Values (a)													
			Potential Carcinogenic Effects						Noncarcinogenic Effects							
Constituent	**CAS No**	**Units**	SFO (mg/kg-day)$^{-1}$	key	Study Type	IUR (ug/m^3)$^{-1}$	key	Study Type	RfD_o (mg/kg-day)	key	Study Type	UF	RfC_i (mg/m^3)	key	Study Type	UF
Arsenic	7440-38-2	mg/kg	1.50E+00	I	Human	4.30E-03	I	Human	3.00E-04	I	Human	3	1.50E-05	C	Human	30
Antimony (b)	7440-36-0	mg/kg							4.00E-04	I	Animal	1000				
Barium	7440-39-3	mg/kg							2.00E-01	I	Animal	300	5.00E-04	H	Animal	1000
Beryllium	7440-41-7	mg/kg				2.40E-03	I	Human	2.00E-03	I	Animal	300	2.00E-05	I	Human	10
Cadmium	7440-43-9	mg/kg				1.80E-03	I	Human	1.00E-03	I	Human	10	2.00E-05	C	Human	30
Chromium-6 (c)	18540-29-9	mg/kg	5.00E-01	J	Human	8.40E-02	S	Human	3.00E-03	I	Animal	300	1.00E-04	I	Animal	300
Chromium-6 (d)	18540-29-9	mg/kg				1.20E-02	I	Human	3.00E-03	I	Animal	300	1.00E-04	I	Animal	300
Chromium-3 (e)	16065-83-1	mg/kg							1.50E+00	I	Animal	100				
Cobalt	7440-48-4	mg/kg				9.00E-03	P	Animal	3.00E-04	P	Human	10	6.00E-06	P	Human	300
Copper	7440-50-8	mg/kg							4.00E-02	H	Human	NA				
Lead (h)	7439-92-1	mg/kg								L						
Lithium	7439-93-2	mg/kg							2.00E-03	P	Human	1000				
Manganese (f)	7439-96-5	mg/kg							2.40E-02	S	Human	1	5.00E-05	I	Human	1000
Mercury (g)	7487-94-7	mg/kg							3.00E-04	I	Animal	1000	3.00E-05	C	Human	300
Molybdenum	7439-98-7	mg/kg							5.00E-03	I	Human	30				
Nickel	7440-02-0	mg/kg				2.60E-04	C	Human	2.00E-02	I	Animal	300	9.00E-05	A	Animal	300
Selenium	7782-49-2	mg/kg							5.00E-03	I	Human	3	2.00E-02	C	Human	3
Strontium	7440-24-6	mg/kg							6.00E-01	I	Animal	300				
Thallium	7440-28-0	mg/kg							1.00E-05	X	Animal	3000				
Uranium	NA	mg/kg							3.00E-03	I	Animal	1000				
Vanadium	NA	mg/kg							5.00E-03	S	Animal	100				
Zinc	7440-66-6	mg/kg							3.00E-01	I	Human	3				

Notes:
ATSDR - Agency for Toxic Substances and Disease Registry.
Cal EPA - California EPA.
CAS - Chemical Abstracts Service.
HEAST - Health Effects Assessment Summary Tables.
IRIS - Integrated Risk Information System.
IUR - Cancer Inhalation Unit Risk Value.
RSL - Regional Screening Level.
RfDo - Oral Noncancer Reference Dose.
RfCi - Inhalation Reference Concentration.
SFO - Oral Cancer Slope Factor.
USEPA - US Environmental Protection Agency.
UF - Uncertainty Factor.
Key: I = IRIS; P = PPRTV; A = ATSDR; C = Cal EPA; X = PPRTV Appendix; H = HEAST; J = New Jersey;
S = see RSL user guide Section 5; L = see RSL user guide on lead.
(a) - USEPA, 2012. Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012. Values for residential soil.
http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm.
(b) - RSLs for metallic antimony.
(c) - RSLs for hexavalent chromium. Cancer values based on toxcity data not presented in the Integrated Risk Information System.
(d) - Alternative screening level calculated for hexavalent chromium using RSL calculator and current dose-response data
from the Integrated Risk Information System. Available at: http://www.epa.gov/IRIS/
(e) - RSLs for trivalent chromium.
(f) - RSLs for manganese (non-diet).
(g) - RSLs for mercuric chloride.
(h) - Lead is evaluated by USEPA using an integrated exposure uptake biokinetic (IEUBK) model.

Table 17
Comparison of Regional Screening Levels for Chromium
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Constituent		Units	Residential Soil Regional Screening Level (a) (e)			
			Noncarcinogenic	Potentially Carcinogenic		
			Hazard Quotient of 1	10^{-6} Risk Level	10^{-5} Risk Level	10^{-4} Risk Level
Chromium-6	(b)	mg/kg	230	0.29	2.9	29
Chromium-6	(c)	mg/kg	235	109	1090	10900
Chromium-3	(d)	mg/kg	120,000	NC	NC	NC

Notes:
NC - Not Calculated; not a potential carcinogen.
RSL - Regional Screening Level.
(a) - USEPA, 2012. Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012. Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm.
(b) - RSLs for hexavalent chromium (Chromium-6). Based on toxcity data not presented in the Integrated Risk Information System.
(c) - Alternative screening level calculated for hexavalent chromium using RSL calculator and current dose-response data from the Integrated Risk Information System.
(d) - RSLs for trivalent chromium (Chromium-3).
(e) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.

Table 18
Basis of USEPA Regional Screening Levels (RSLs) for Residential Soils
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

			Residential Soil Regional Screening Level (a) (i)										
			Carcinogenic Target Risk (TR) = 1E-06					Noncancer Hazard Index (HI) = 1					
			Route of Exposure				Basis of Screening Level	Route of Exposure				Basis Screening Level	
Constituent	**CAS No**	**Units**	**ing**	**derm (k)**	**inh**	**Carcinogenic RSL**		**ing**	**derm (k)**	**inh**	**Noncarcinogenic RSL**		**Noncancer Target Endpoint Oral (j)**
Arsenic	7440-38-2	mg/kg	0.43	4.5	770	0.39	O/D/I	23	280	21000	22	O/D/I	Hyperpigmentation, Kertosis and Possible Vascular Complications
Antimony (b)	7440-36-0	mg/kg				NC		31			31	O	Longevity, blood glucose, and cholesterol
Barium	7440-39-3	mg/kg				NC		16000		710000	15,000	O/I	Nephropathy
Beryllium	7440-41-7	mg/kg			1400	1400	I	160		28000	160	O/I	Small intestinal lesions
Cadmium	7440-43-9	mg/kg			1800	1800	I	78	700	28000	70	O/D/I	Significant proteinuria
Chromium-6 (c)	18540-29-9	mg/kg	0.3		16	0.29	I/O	230		140000	230	O/I	None reported
Chromium-6 (d)	18540-29-9	mg/kg			109	109	I	235		142000	235	O/I	None reported
Chromium-3 (e)	16065-83-1	mg/kg				NC		120000			120,000	O	None reported
Cobalt	7440-48-4	mg/kg			370	370	I	23		8500	23	O/I	Thyroid toxicity
Copper	7440-50-8	mg/kg				NC		3100			3,100	O	Gastrointestinal irritation
Lead	7439-92-1	mg/kg				NC					400	O	(h)
Lithium	7439-93-2	mg/kg				NC		160			160	O	Adverse renal effects
Manganese (f)	7439-96-5	mg/kg				NC		1900		71000	1,800	O/I	CNS Effects (Other Effect: Impairment of Neurobehavioral Function)
Mercury (g)	7487-94-7	mg/kg				NC		23		43000	23	O/I	Autoimmune effects
Molybdenum	7439-98-7	mg/kg				NC		390			390	O	Increased uric acid levels (kidney effects)
Nickel	7440-02-0	mg/kg			13000	13000	I	1600		130000	1,500	O/I	Decreased body and organ weights
Selenium	7782-49-2	mg/kg				NC		390		28000000	390	O/I	Clinical Selenosis (Skin, Nails, Hair, Behavioral)
Strontium	7440-24-6	mg/kg				NC		47000			47,000	O	Rachic bone
Thallium	7440-28-0	mg/kg				NC		0.78			0.78	O	Hair follicle atrophy
Uranium	NA	mg/kg				NC		230		430000	230	O/I	Initial body weight loss; moderate nephrotoxicity
Vanadium	NA	mg/kg				NC		390			390	O	Decreased hair cystine
Zinc	7440-66-6	mg/kg				NC		23000			23,000	O	Decreases in erythrocyte Cu, Zn-superoxide dismutase (ESOD) activity

Notes:
CAS - Chemical Abstracts Service.
D - Screening level includes the dermal pathway.
I - Screening level includes the inhalation pathway.
NA - Not Available.
NC - Not Calculated; not a potential carcinogen.
O - Screening level includes the oral pathway.
RSL - Regional Screening Level.
USEPA - US Environmental Protection Agency.
ing = Ingestion.
derm - Dermal.
inh - Inhalation.
(a) - USEPA, 2012. Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012. Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm.
(b) - RSLs for metallic antimony.
(c) - RSLs for hexavalent chromium. Based on toxcity data not presented in the Integrated Risk Information System.
(d) - Alternative screening level calculated for hexavalent chromium using RSL calculator and current dose-response data from the Integrated Risk Information System. Available at: http://www.epa.gov/IRIS/
(e) - RSLs for trivalent chromium.
(f) - RSLs for manganese (non-diet).
(g) - RSLs for mercuric chloride.
(h) - Lead is not included in the calculation of target-endpoint specific hazard quotients.
(i) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.
(j) - Where the RSL is based on multiple pathways, the oral pathway is the driver. Therefore, target endpoints are based on the oral pathway.
(k) - USEPA has determined that dermal exposure for most metals is negligible, as they are absorbed poorly from soils. Dermal RSLs are provided only for those cosnttiuents for which USEPA has developed non-zero dermal absoprtion factors. See the supplementary USEPA residential soil RSL table (USEPA, 2012a).

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Table 19
Exposure Point Concentration (EPC) Selection Table - Alaska Power Plant Fly Ash/Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Constituent	Units	FOD	Minimum Detect	Maximum Detect	Mean Detect (a)	UCL Selected (b)	UCL (d)	
Antimony	mg/kg	19: 19	4.21	12.1	7.31	95% Student's-t UCL	8.301	
Arsenic	mg/kg	19: 19	7.3	32.9	18.77	95% Approximate Gamma UCL	22.45	
Barium	mg/kg	19: 19	4290	5730	4959	95% Student's-t UCL	5138	
Beryllium	mg/kg	19: 19	1.69	3.16	2.34	95% Student's-t UCL	2.495	
Cadmium	mg/kg	19: 19	0.38	1.84	0.96	95% Chebyshev (Mean, Sd) UCL	1.434	
Chromium	mg/kg	19: 19	247	925	407.50	95% Modified-t UCL	487.6	
Cobalt	mg/kg	19: 19	24.6	32.6	28.78	95% Student's-t UCL	29.8	
Copper	mg/kg	19: 19	114	197	153	95% Student's-t UCL	162.5	
Lead	mg/kg	19: 19	14.4	77	39.08	95% H-UCL	39.08	(e)
Lithium	mg/kg	19: 19	13.2	30.4	22.96	95% Student's-t UCL	25.06	
Manganese	mg/kg	19: 19	731	966	873.00	95% Student's-t UCL	900.6	
Mercury	mg/kg	19: 19	0.123	1.15	0.46	95% Approximate Gamma UCL	0.615	
Molybdenum	mg/kg	19: 19	19.6	45.4	34.35	95% Student's-t UCL	36.98	
Nickel	mg/kg	19: 19	159	280	226.80	95% Student's-t UCL	239.3	
Selenium	mg/kg	19: 19	1.25	7.14	3.29	95% Approximate Gamma UCL	4.088	
Strontium	mg/kg	19: 19	1240	1830	1479	95% Student's-t UCL	1566	
Thallium	mg/kg	19: 19	0.312	1.99	0.73	95% Approximate Gamma UCL	0.925	
Uranium	mg/kg	19: 19	0.682	1.1	0.92	95% Student's-t UCL	0.967	
Vanadium	mg/kg	19: 19	203	418	265.50	95% Modified-t UCL	290.7	
Zinc	mg/kg	19: 19	33.1	233	76.12	95% Modified-t UCL	96.16	

Notes:
EPC - Exposure Point Concentration.
FOD - Frequency of Detection - Number of detected results: Total number of samples.
UCL - Upper confidence limit on the arithmetic mean.
(a) - Arithmetic mean.
(b) - Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated using ProUCL and data from (c). The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL Version 4.1 (USEPA, 2011).
(c) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(d) - The EPC is equal to the lower of the UCL and the maximum detected concentration. The EPC is the UCL unless otherwise noted.
(e) - The EPC for lead is equal to the mean detected concentration for appropriate comparison with the screening level.

Table 20
Exposure Point Concentration (EPC) Selection Table - Indiana Power Plant Fly Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Constituent	Units	FOD	Minimum Detect	Maximum Detect	Mean Detect (a)	UCL Selected (b)	UCL (d)	
Antimony	mg/kg	13:13	1.96	22.4	4.12	95% Chebyshev (Mean, Sd) UCL	10.81	
Arsenic	mg/kg	13:13	20.2	56.3	26.13	95% Modified-t UCL	31.07	
Barium	mg/kg	13:13	336	422	379.50	95% Student's-t UCL	393.6	
Beryllium	mg/kg	13:13	2.32	32.7	5.33	95% Chebyshev (Mean, Sd) UCL	15.32	
Cadmium	mg/kg	13:13	0.79	3.29	1.15	95% Modified-t UCL	1.507	
Chromium	mg/kg	13:13	78.2	984	169.10	95% Chebyshev (Mean, Sd) UCL	466.1	
Cobalt	mg/kg	13:13	22.5	264	45.31	95% Chebyshev (Mean, Sd) UCL	124.8	
Copper	mg/kg	13:13	156	692	223.80	95% Modified-t UCL	300.5	
Lead	mg/kg	13:13	22.1	293	50.15	95% Chebyshev (Mean, Sd) UCL	50.15	(e)
Lithium	mg/kg	13:13	21.6	560	68.38	95% Chebyshev (Mean, Sd) UCL	247.2	
Manganese	mg/kg	13:13	105	723	200.80	95% Modified-t UCL	286.3	
Mercury	mg/kg	13:13	0.0127	0.104	0.04	95% Approximate Gamma UCL	0.0511	
Molybdenum	mg/kg	13:13	5.32	90.5	13.74	95% Chebyshev (Mean, Sd) UCL	41.9	
Nickel	mg/kg	13:13	58.2	572	107.90	95% Chebyshev (Mean, Sd) UCL	276.8	
Selenium	mg/kg	13:13	4.06	22.5	8.62	95% Approximate Gamma UCL	11.2	
Strontium	mg/kg	13:13	319	638	418.70	95% Approximate Gamma UCL	474.8	
Thallium	mg/kg	13:13	0.382	21	2.13	95% Chebyshev (Mean, Sd) UCL	8.992	
Uranium	mg/kg	13:13	5.33	34.1	8.67	95% Modified-t UCL	12.81	
Vanadium	mg/kg	13:13	262	1660	419.60	95% Modified-t UCL	622.1	
Zinc	mg/kg	13:13	122	848	238.20	95% Modified-t UCL	339.4	

Notes:
EPC - Exposure Point Concentration.
FOD - Frequency of Detection - Number of detected results: Total number of samples.
UCL - Upper confidence limit on the arithmetic mean.
(a) - Arithmetic mean.
(b) - Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated using ProUCL and data from (c). The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL Version 4.1 (USEPA, 2011).
(c) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(d) - The EPC is equal to the lower of the UCL and the maximum detected concentration. The EPC is the UCL unless otherwise noted.
(e) - The EPC for lead is equal to the mean detected concentration for appropriate comparison with the screening level per USEPA guidance.

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Table 21
Exposure Point Concentration (EPC) Selection Table - New Mexico Power Plant Fly Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Constituent	Units	FOD	Minimum Detect	Maximum Detect	Mean Detect (a)	UCL Selected (b)	UCL (d)
Antimony	mg/kg	16:16	2.79	3.78	3.27	95% Student's-t UCL	3.405
Arsenic	mg/kg	16:16	16.8	22.2	19.58	95% Student's-t UCL	20.27
Barium	mg/kg	16:16	1230	1950	1664.00	95% Student's-t UCL	1742
Beryllium	mg/kg	16:16	5.06	6.69	5.75	95% Student's-t UCL	5.952
Cadmium	mg/kg	16:16	0.42	0.68	0.53	95% Student's-t UCL	0.563
Chlorine	mg/kg	15:16	1.2	8.58	3.59	95% KM (BCA) UCL	4.366
Chromium	mg/kg	16:16	33.7	45.9	37.68	95% Modified-t UCL	39.33
Cobalt	mg/kg	16:16	14.5	18.3	15.84	95% Approximate Gamma UCL	16.37
Copper	mg/kg	16:16	60.8	68.7	65.01	95% Student's-t UCL	66.06
Lead	mg/kg	16:16	53.8	67.5	61.88	95% Student's-t UCL	61.88 (e)
Lithium	mg/kg	16:16	91.8	116	101.90	95% Student's-t UCL	104.7
Manganese	mg/kg	16:16	180	222	197.50	95% Student's-t UCL	202.2
Mercury	mg/kg	16:16	0.0648	0.263	0.14	95% Student's-t UCL	0.168
Molybdenum	mg/kg	16:16	7.94	9.35	8.63	95% Student's-t UCL	8.825
Nickel	mg/kg	16:16	17.3	22.9	19.88	95% Student's-t UCL	20.54
Selenium	mg/kg	16:16	1.03	12.2	8.39	95% Student's-t UCL	9.645
Strontium	mg/kg	16:16	345	476	402.10	95% Student's-t UCL	415.1
Thallium	mg/kg	16:16	1.07	2.9	1.55	95% Modified-t UCL	1.757
Uranium	mg/kg	16:16	12	13.5	12.70	95% Student's-t UCL	12.88
Vanadium	mg/kg	16:16	106	128	113.90	95% Student's-t UCL	116.5
Zinc	mg/kg	16:16	70.4	83.5	77.67	95% Student's-t UCL	79.49

Notes:
EPC - Exposure Point Concentration.
FOD - Frequency of Detection - Number of detected results: Total number of samples.
UCL - Upper confidence limit on the arithmetic mean.
(a) - Arithmetic mean.
(b) - Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated using ProUCL and data from (c). The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL Version 4.1 (USEPA, 2011).
(c) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(d) - The EPC is equal to the lower of the UCL and the maximum detected concentration. The EPC is the UCL unless otherwise noted.
(e) - The EPC for lead is equal to the mean detected concentration for appropriate comparison with the screening level per USEPA guidance.

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Table 22
Exposure Point Concentration (EPC) Selection Table - Ohio Power Plant Fly Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Constituent	Units	FOD	Minimum Detect	Maximum Detect	Mean Detect (a)	UCL Selected (b)	UCL (d)
Antimony	mg/kg	13:13	0.982	5.3	2.05	95% Modified-t UCL	2.603
Arsenic	mg/kg	13:13	33.7	93.8	59.04	95% Student's-t UCL	66.33
Barium	mg/kg	13:13	464	608	530.20	95% Student's-t UCL	554.7
Beryllium	mg/kg	13:13	8.03	15.4	11.26	95% Student's-t UCL	12.25
Cadmium	mg/kg	13:13	0.312	0.963	0.74	95% Student's-t UCL	0.821
Chromium	mg/kg	13:13	118	181	147.80	95% Modified-t UCL	160.8
Cobalt	mg/kg	13:13	27.6	46.4	36.09	95% Student's-t UCL	39.37
Copper	mg/kg	13:13	55.1	193	85.22	95% Approximate Gamma UCL	101.8
Lead	mg/kg	13:13	21.4	50.4	39.07	95% Student's-t UCL	39.07 (e)
Lithium	mg/kg	13:13	74	140	110.00	95% Student's-t UCL	121.1
Manganese	mg/kg	13:13	193	333	252.80	95% Student's-t UCL	278.3
Mercury	mg/kg	13:13	0.0167	0.0561	0.03	95% Student's-t UCL	0.0376
Molybdenum	mg/kg	13:13	7.15	18.4	10.47	95% Modified-t UCL	11.88
Nickel	mg/kg	13:13	79.5	123	97.95	95% Student's-t UCL	104.9
Selenium	mg/kg	13:13	3.49	5.47	4.13	95% Student's-t UCL	4.392
Strontium	mg/kg	13:13	587	763	666.60	95% Student's-t UCL	691.1
Thallium	mg/kg	13:13	1.06	6.13	3.43	95% Student's-t UCL	3.995
Uranium	mg/kg	13:13	5.2	9.58	7.66	95% Student's-t UCL	8.408
Vanadium	mg/kg	13:13	179	317	248.00	95% Student's-t UCL	271.4
Zinc	mg/kg	13:13	62.7	141	111.00	95% Student's-t UCL	121.9

Notes:
EPC - Exposure Point Concentration.
FOD - Frequency of Detection - Number of detected results: Total number of samples.
UCL - Upper confidence limit on the arithmetic mean.
(a) - Arithmetic mean.
(b) - Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated using ProUCL and data from (c). The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL Version 4.1 (USEPA, 2011).
(c) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(d) - The EPC is equal to the lower of the UCL and the maximum detected concentration. The EPC is the UCL unless otherwise noted.
(e) - The EPC for lead is equal to the mean detected concentration for appropriate comparison with the screening level per USEPA guidance.

Table 23
Exposure Point Concentration (EPC) Selection Table - Wyoming Power Plant Fly Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Constituent	Units	FOD	Minimum Detect	Maximum Detect	Mean Detect (a)	UCL Selected (b)	UCL (d)	
Antimony	mg/kg	15:15	1.65	2.11	1.92	95% Student's-t UCL	1.986	
Arsenic	mg/kg	15:15	14.6	22	19.41	95% Student's-t UCL	20.25	
Barium	mg/kg	15:15	2980	3370	3174.00	95% Student's-t UCL	3212	
Beryllium	mg/kg	15:15	2.07	3.1	2.71	95% Student's-t UCL	2.815	
Cadmium	mg/kg	15:15	0.699	0.895	0.80	95% Student's-t UCL	0.832	
Chromium	mg/kg	15:15	54.1	102	83.64	95% Student's-t UCL	88.46	
Cobalt	mg/kg	15:15	31.4	43.5	38.72	95% Student's-t UCL	40.17	
Copper	mg/kg	15:15	118	171	148.90	95% Student's-t UCL	155.3	
Lead	mg/kg	15:15	25	33.1	28.37	95% Student's-t UCL	28.37	(e)
Lithium	mg/kg	15:15	21.8	32.9	29.17	95% Student's-t UCL	30.39	
Manganese	mg/kg	15:15	145	283	214.90	95% Student's-t UCL	234.5	
Mercury	mg/kg	15:15	0.0212	0.971	0.60	95% Chebyshev (Mean, Sd) UCL	0.971	(f)
Molybdenum	mg/kg	15:15	4.95	6.09	5.69	95% Student's-t UCL	5.822	
Nickel	mg/kg	15:15	106	180	157.60	95% Student's-t UCL	165.3	
Selenium	mg/kg	15:15	11.2	13.5	12.35	95% Student's-t UCL	12.66	
Strontium	mg/kg	15:15	2180	2400	2293.00	95% Student's-t UCL	2319	
Thallium	mg/kg	15:15	0.472	0.747	0.59	95% Student's-t UCL	0.624	
Uranium	mg/kg	15:15	7.29	11.2	8.75	95% Approximate Gamma UCL	9.266	
Vanadium	mg/kg	15:15	218	376	312.30	95% Student's-t UCL	333.2	
Zinc	mg/kg	15:15	87.9	186	135.20	95% Student's-t UCL	147.5	

Notes:
EPC - Exposure Point Concentration.
FOD - Frequency of Detection - Number of detected results: Total number of samples.
UCL - Upper confidence limit on the arithmetic mean.
(a) - Arithmetic mean.
(b) - Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated using ProUCL and data from (c). The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL Version 4.1 (USEPA, 2011).
(c) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(d) - The EPC is equal to the lower of the UCL and the maximum detected concentration. The EPC is the UCL unless otherwise noted.
(e) - The EPC for lead is equal to the mean detected concentration for appropriate comparison with the screening level per USEPA guidance.
(f) - Recommended UCL exceeds the maximum detected concentration. Therefore, the maximum detected concentration is used as the EPC.

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Table 24
Exposure Point Concentration (EPC) Selection Table - New Mexico Power Plant Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Constituent	Units	FOD	Minimum Detect	Maximum Detect	Mean (a)	UCL Selected (b)	UCL (d)	
Antimony	mg/kg	18:18	0.401	0.911	0.62	95% Student's-t UCL	0.692	
Arsenic	mg/kg	18:18	1.24	18.1	3.05	95% Chebyshev (Mean, Sd) UCL	6.955	
Barium	mg/kg	18:18	983	2000	1415.00	95% Student's-t UCL	1529	
Beryllium	mg/kg	18:18	3.41	5.33	4.16	95% Student's-t UCL	4.389	
Cadmium	mg/kg	0:19	ND	ND	ND	NC	NC	
Chromium	mg/kg	18:18	17.5	30.1	22.31	95% Approximate Gamma UCL	23.93	
Cobalt	mg/kg	18:18	7.29	10.6	8.58	95% Student's-t UCL	8.999	
Copper	mg/kg	18:18	40.4	47.5	42.87	95% Student's-t UCL	43.57	
Lead	mg/kg	18:18	16.5	23	19.22	95% Student's-t UCL	19.22	(e)
Lithium	mg/kg	18:18	82.6	120	98.37	95% Student's-t UCL	102.5	
Manganese	mg/kg	18:18	159	308	238.10	95% Student's-t UCL	252.7	
Mercury	mg/kg	3:18	0.0307	0.155	0.10	NC	0.155	(f)
Molybdenum	mg/kg	18:18	2.15	3.64	2.71	95% Student's-t UCL	2.871	
Nickel	mg/kg	18:18	28.8	49.5	35.75	95% Student's-t UCL	38.14	
Selenium	mg/kg	16:18	0.121	0.626	0.23	95% KM (BCA) UCL	0.271	
Strontium	mg/kg	18:18	270	408	328.90	95% Student's-t UCL	344.9	
Thallium	mg/kg	11:18	0.115	1.96	0.73	95% KM (Percentile Bootstrap) UCL	0.727	
Uranium	mg/kg	18:18	9.03	11	9.66	95% Modified-t UCL	9.904	
Vanadium	mg/kg	18:18	69.4	95.5	77.53	95% Modified-t UCL	80.81	
Zinc	mg/kg	18:18	26.5	53.2	32.38	95% Approximate Gamma UCL	34.84	

Notes:
EPC - Exposure Point Concentration.
FOD - Frequency of Detection - Number of detected results: Total number of samples.
UCL - Upper confidence limit on the arithmetic mean.
(a) - Arithmetic mean.
(b) - Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated using ProUCL and data from (c). The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL Version 4.1 (USEPA, 2011).
(c) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(d) - The EPC is equal to the lower of the UCL and the maximum detected concentration. The EPC is the UCL unless otherwise noted.
(e) - The EPC for lead is equal to the mean detected concentration for appropriate comparison with the screening level per USEPA guidance.
(f) - Maximum detected value used.

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Table 25
Exposure Point Concentration (EPC) Selection Table - Ohio Power Plant Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Constituent	Units	FOD	Minimum Detect	Maximum Detect	Mean (a)	UCL Selected (b)	UCL (d)	
Antimony	mg/kg	15:15	0.867	3.2	1.29	95% Modified-t UCL	1.599	
Arsenic	mg/kg	15:15	3.6	12.9	5.98	95% Approximate Gamma UCL	7.278	
Barium	mg/kg	15:15	474	518	491.90	95% Student's-t UCL	497.1	
Beryllium	mg/kg	15:15	7.72	10.3	9.02	95% Student's-t UCL	9.394	
Cadmium	mg/kg	13:15	0.104	0.169	0.13	95% KM (t) UCL	0.131	
Chromium	mg/kg	15:15	266	461	377.00	95% Student's-t UCL	397.4	
Cobalt	mg/kg	15:15	34.5	37.7	36.23	95% Student's-t UCL	36.61	
Copper	mg/kg	15:15	54	69.1	61.37	95% Student's-t UCL	63.19	
Lead	mg/kg	15:15	13.9	40	17.45	95% Modified-t UCL	17.45	(e)
Lithium	mg/kg	15:15	86.4	98.6	92.80	95% Student's-t UCL	94.31	
Manganese	mg/kg	14:15	296	347	322.60	95% KM (Percentile Bootstrap) UCL	327.7	
Mercury	mg/kg	2:15	0.0123	0.0207	0.02	NC	0.0207	(f)
Molybdenum	mg/kg	15:15	6.31	10.2	8.12	95% Student's-t UCL	8.599	
Nickel	mg/kg	15:15	162	240	202.30	95% Student's-t UCL	211.2	
Selenium	mg/kg	7:14	0.129	0.755	0.27	95% KM (t) UCL	0.283	
Strontium	mg/kg	15:15	554	636	601.10	95% Student's-t UCL	614.4	
Thallium	mg/kg	15:15	0.446	0.684	0.55	95% Student's-t UCL	0.579	
Uranium	mg/kg	15:15	5.27	7.08	5.75	95% Approximate Gamma UCL	5.949	
Vanadium	mg/kg	15:15	192	221	209.20	95% Student's-t UCL	213.4	
Zinc	mg/kg	15:15	55.9	72.9	61.17	95% Modified-t UCL	63.01	

Notes:
EPC - Exposure Point Concentration.
FOD - Frequency of Detection - Number of detected results: Total number of samples.
UCL - Upper confidence limit on the arithmetic mean.
(a) - Arithmetic mean.
(b) - Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated using ProUCL and data from (c). The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL Version 4.1 (USEPA, 2011).
(c) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(d) - The EPC is equal to the lower of the UCL and the maximum detected concentration. The EPC is the UCL unless otherwise noted.
(e) - The EPC for lead is equal to the mean detected concentration for appropriate comparison with the screening level per USEPA guidance.
(f) - Maximum detected value was used

Table 26
Exposure Point Concentration (EPC) Selection Table - Wyoming Power Plant Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Constituent	Units	FOD	Minimum Detect	Maximum Detect	Mean (a)	UCL Selected (b)	UCL (d)	
Antimony	mg/kg	15:15	0.568	1.05	0.75	95% Student's-t UCL	0.801	
Arsenic	mg/kg	15:15	4.99	7.73	6.48	95% Student's-t UCL	6.85	
Barium	mg/kg	15:15	2440	2990	2753.00	95% Student's-t UCL	2828	
Beryllium	mg/kg	15:15	2.99	3.78	3.37	95% Student's-t UCL	3.488	
Cadmium	mg/kg	14:15	0.138	0.425	0.20	95% KM (Chebyshev) UCL	0.295	
Chromium	mg/kg	15:15	62.8	89.9	76.23	95% Student's-t UCL	80.5	
Cobalt	mg/kg	15:15	36.6	55	46.03	95% Student's-t UCL	48.3	
Copper	mg/kg	15:15	110	148	130.50	95% Student's-t UCL	135.4	
Lead	mg/kg	15:15	7.59	10.5	9.27	95% Student's-t UCL	9.27	(e)
Lithium	mg/kg	15:15	29.5	39.3	34.85	95% Student's-t UCL	36.23	
Manganese	mg/kg	15:15	145	282	249.60	95% Student's-t UCL	269.3	
Mercury	mg/kg	10:15	0.0145	0.111	0.04	95% KM (Percentile Bootstrap) UCL	0.0424	
Molybdenum	mg/kg	15:15	3	3.37	3.19	95% Student's-t UCL	3.239	
Nickel	mg/kg	15:15	65.3	255	93.91	95% Modified-t UCL	117.6	
Selenium	mg/kg	14:15	0.169	1.28	0.61	95% KM (t) UCL	0.75	
Strontium	mg/kg	15:15	2370	2680	2539.00	95% Student's-t UCL	2577	
Thallium	mg/kg	15:15	0.102	0.294	0.17	95% Student's-t UCL	0.188	
Uranium	mg/kg	15:15	8.44	9.55	8.98	95% Student's-t UCL	9.143	
Vanadium	mg/kg	15:15	279	591	411.30	95% Modified-t UCL	466.8	
Zinc	mg/kg	15:15	51.7	152	84.93	95% Student's-t UCL	98.88	

Notes:
EPC - Exposure Point Concentration.
FOD - Frequency of Detection - Number of detected results: Total number of samples.
UCL - Upper confidence limit on the arithmetic mean.
(a) - Arithmetic mean.
(b) - Sample size was greater than or equal to 10 and the number of detected values was greater than or equal to 6, therefore, a 95% UCL was calculated using ProUCL and data from (c). The UCL shown is the one recommended by ProUCL. If more than one UCL was recommended, the higher UCL was selected. ProUCL Version 4.1 (USEPA, 2011).
(c) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(d) - The EPC is equal to the lower of the UCL and the maximum detected concentration. The EPC is the UCL unless otherwise noted.
(e) - The EPC for lead is equal to the mean detected concentration for appropriate comparison with the screening level per USEPA guidance.

Table 27

Summary Statistics - Alaska, Indiana, New Mexico, Ohio and Wyoming Power Plants Fly Ash

Coal Ash Material Safety - A Health Risk-Based Evaluation

American Coal Ash Association

Five State Summary Statistics for Fly Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	76:76	0.982	22.4	3.947	2.88	1.695	2.88	8.595
Arsenic	76:76	7.3	93.8	27.21	20.95	14.55	20.95	57.95
Barium	76:76	336	5730	2372	1745	389	1745	5050
Beryllium	76:76	1.69	32.7	5.166	2.875	2.215	2.875	11.35
Cadmium	76:76	0.312	3.29	0.831	0.791	0.462	0.791	1.24
Chromium	76:76	33.7	984	180.5	100.6	36.1	100.6	360
Cobalt	76:76	14.5	264	32.1	28.65	15.35	28.65	41.25
Copper	76:76	55.1	692	134.2	139.5	64.6	139.5	186.5
Lead	76:76	14.4	293	43.66	33.8	23.65	33.8	64.85
Lithium	76:76	13.2	560	63.47	30.15	21.75	30.15	110.5
Manganese	76:76	105	966	379.8	217.5	158.5	217.5	908
Mercury	76:76	0.0127	1.15	0.276	0.128	0.0243	0.128	0.844
Molybdenum	76:76	4.95	90.5	15.67	8.705	5.755	8.705	35.25
Nickel	76:76	17.3	572	127.2	107	20	107	234.5
Selenium	76:76	1.03	22.5	7.208	6.09	2.175	6.09	12.55
Strontium	76:76	319	2400	1093	700.5	375	700.5	2290
Thallium	76:76	0.312	21	1.576	0.77	0.418	0.77	3.295
Uranium	76:76	0.682	34.1	7.422	7.37	0.848	7.37	12.7
Vanadium	76:76	106	1660	266.2	251	111.5	251	363.5
Zinc	76:76	33.1	848	121.8	106	51.55	106	184.5

Notes:

FOD - Frequency of Detection - Number of detected results: Total number of samples.

(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011).

(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/. The specific datasets used from this source are detailed in the report text.

Table 28
Summary Statistics - New Mexico, Ohio and Wyoming Power Plants Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

New Mexico, Ohio and Wyoming Power Plants Summary Statistics for Bottom Ash (a) (b)								
Constituent	**FOD**	**Minimum Detect**	**Maximum Detect**	**Mean Detect**	**Median**	**10%ile**	**50%ile(Q2)**	**90%ile**
Antimony	48:48	0.401	3.2	0.869	0.797	0.488	0.797	1.15
Arsenic	48:48	1.24	18.1	5.036	4.775	1.744	4.775	7.344
Barium	48:48	474	2990	1545	1435	486.8	1435	2840
Beryllium	48:48	2.99	10.3	5.429	4.085	3.206	4.085	9.316
Cadmium	27:48	0.104	0.425	0.165	0.148	0.1132	0.148	0.2056
Chromium	48:48	17.5	461	150	72	19.47	72	397.5
Cobalt	48:48	7.29	55	28.92	36.05	7.818	36.05	49.46
Copper	48:48	40.4	148	76.03	59.8	41.81	59.8	135.6
Lead	48:48	7.59	40	15.56	15.8	8.79	15.8	20.01
Lithium	48:48	29.5	120	76.78	90.15	33.64	90.15	106
Manganese	47:48	145	347	266.9	266	214.8	266	324
Mercury	15:48	0.0123	0.155	0.047	0.0229	0.01474	0.0229	0.1122
Molybdenum	48:48	2.15	10.2	4.55	3.215	2.493	3.215	8.465
Nickel	48:48	28.8	255	106	74.45	31.29	74.45	214.6
Selenium	37:48	0.121	1.28	0.382	0.253	0.136	0.253	0.8814
Strontium	48:48	270	2680	1105	588.5	291.7	588.5	2563
Thallium	41:48	0.102	1.96	0.459	0.446	0.128	0.446	0.747
Uranium	48:48	5.27	11	8.229	9.045	5.597	9.045	9.96
Vanadium	48:48	69.4	591	223	206.5	72.65	206.5	512.1
Zinc	48:48	26.5	152	57.8	57.85	28.19	57.85	91.44

Notes:
FOD - Frequency of Detection - Number of detected results: Total number of samples.
(a) - Statistics calculated using ProUCL version 4.1 (USEPA, 2011). ProUCL does not calculate summary percentiles for datasets with non-detect values. Therefore, cadmium, mercury, manganese, selenium and thallium percentiles calculated using Microsoft Excel for detected values only.
(b) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/. The specific datasets used from this source are detailed in the report.

Table 29
Cumulative Risk Screen - Alaska Power Plant Fly Ash/Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

AECOM

		Alaska Power Plant Fly Ash/Bottom Ash (h)				
Potential Carcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Potential Carcinogenic Risk (c)**	
Arsenic	mg/kg	2.25E+01	3.90E-01	O/D/I	6E-05	
Beryllium	mg/kg	2.50E+00	1.40E+03	I	2E-09	
Cadmium	mg/kg	1.43E+00	1.80E+03	I	8E-10	
Chromium-6 (g)	mg/kg	4.88E+02	1.09E+02	I	4E-06	
Cobalt	mg/kg	2.98E+01	3.70E+02	I	8E-08	
Nickel	mg/kg	2.39E+02	1.30E+04	I	2E-08	
			Total Potential Carcinogenic Risk:		6E-05	**Total within USEPA target risk range (j)**

		Alaska Power Plant Fly Ash/Bottom Ash (h)				
Noncarcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Hazard Quotient (c)**	**Non-Cancer Oral Target Endpoint**
Arsenic	mg/kg	2.25E+01	2.20E+01	O/D/I	1E+00	Skin, Vascular
Antimony	mg/kg	8.30E+00	3.10E+01	O	3E-01	Mortality, Hematological
Barium	mg/kg	5.14E+03	1.50E+04	O/I	3E-01	Kidney
Beryllium	mg/kg	2.50E+00	1.60E+02	O/I	2E-02	Gastrointestinal
Cadmium	mg/kg	1.43E+00	7.00E+01	O/D/I	2E-02	Kidney
Chromium-6 (g)	mg/kg	4.88E+02	2.35E+02	O/I	2E+00	None reported
Cobalt	mg/kg	2.98E+01	2.30E+01	O/I	1E+00	Thyroid
Copper	mg/kg	1.63E+02	3.10E+03	O	5E-02	Gastrointestinal
Lithium	mg/kg	2.51E+01	1.60E+02	O	2E-01	Kidney
Manganese	mg/kg	9.01E+02	1.80E+03	O/I	5E-01	Nervous System
Mercury	mg/kg	6.15E-01	2.30E+01	O/I	3E-02	Immune
Molybdenum	mg/kg	3.70E+01	3.90E+02	O	9E-02	Kidney
Nickel	mg/kg	2.39E+02	1.50E+03	O/I	2E-01	Body weight
Selenium	mg/kg	4.09E+00	3.90E+02	O/I	1E-02	Skin, Nails, Hair, Behavioral
Strontium	mg/kg	1.57E+03	4.70E+04	O	3E-02	Skeletal
Thallium	mg/kg	9.25E-01	7.80E-01	O	1E+00	Hair
Uranium	mg/kg	9.67E-01	2.30E+02	O/I	4E-03	Kidney, Body weight
Vanadium	mg/kg	2.91E+02	3.90E+02	O	7E-01	Hair
Zinc	mg/kg	9.62E+01	2.30E+04	O	4E-03	Hematological
			Total Hazard Index:		8E+00	
Hazard Index by Target Endpoint Hazard (e)						
					2E-01	Body Weight
					7E-02	Gastrointestinal
			Target Endpoint Risk Driver: Thallium		2E+00	Hair
					3E-01	Hematological
					3E-02	Immune
					6E-01	Kidney
					3E-01	Mortality
					1E-02	Nails, Behavioral
					5E-01	Nervous System
			Target Endpoint Risk Driver: Chromium-6 (g)		2E+00	None Reported
					3E-02	Skeletal
					1E+00	Skin
					1E+00	Thyroid
					1E+00	Vascular
Lead	mg/kg	3.91E+01 (k)	4.00E+02		(f)	--

Notes presented on following page.

Notes:

D - Screening level includes the dermal pathway.
I - Screening level includes the inhalation pathway.
O - Screening level includes the oral pathway.

(a) - Constituents that have screening levels for potentially carcinogenic and noncarcinogenic effects are evaluated for both.

(b) - USEPA Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012. Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm

(c) - For noncarcinogens, the hazard quotient is the 95% upper confidence limit concentration divided by the screening level, which is based on a hazard index of one. For potential carcinogens, the potential cancer risk is the 95% upper confidence limit concentration divided by the screening level and multiplied by the target risk level of 1×10^{-6} associated with the RSLs.

(d) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.

(e) - The total hazard index (HI) exceeds one. Therefore, constituents with individual hazard quotients greater than one are identified in bold. Constituent HI's are further refined and summed by target endpoint. Where target endpoint HIs exceed one, driving constituents are also listed. Note that the RSLs for the noncarcinogens listed in this table are driven by the oral pathway. Therefore, the target endpoint listed is based on the oral reference dose.

(f) - Lead is not included in the cumulative screen because the RSL is based on lead modeling, which does not equate to a hazard quotient. Therefore, the lead concentration is compared directly to the RSL.

(g) - It is conservatively assumed that all chromium is in hexavalent form. The screening level for hexavalent chromium was calculated based on current toxicity data available from USEPA's Integrated Risk Information System (IRIS) (see Table 1).

(h) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

(i) - The exposure point concentration is the 95% upper confidence limit on the arithmetic mean. Calculated using USEPA's ProUCL program (version 4.1.01 (USEPA, 2011)) and data from (h), unless otherwise stated.

(j) - USEPA's target risk range is 1×10^{-4} to 1×10^{-6}.

(k) - The exposure point concentration used to evaluate lead per USEPA guidance is the arithmetic mean concentration.

Table 30
Cumulative Risk Screen- Indiana Power Plant Fly Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Assocation

		Indiana Power Plant Fly Ash (h)				
Potential Carcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Potential Carcinogenic Risk (c)**	
Arsenic	mg/kg	3.11E+01	3.90E-01	O/D/I	8E-05	
Beryllium	mg/kg	1.53E+01	1.40E+03	I	1E-08	
Cadmium	mg/kg	1.51E+00	1.80E+03	I	8E-10	
Chromium-6 (g)	mg/kg	4.66E+02	1.09E+02	I	4E-06	
Cobalt	mg/kg	1.25E+02	3.70E+02	I	3E-07	
Nickel	mg/kg	2.77E+02	1.30E+04	I	2E-08	
Total Potential Carcinogenic Risk:					8E-05	**Total within USEPA target risk range (j)**

		Indiana Power Plant Fly Ash (h)				
Noncarcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Hazard Quotient (c)**	**Non-Cancer Oral Target Endpoint**
Arsenic	mg/kg	3.11E+01	2.20E+01	O/D/I	1E+00	Skin, Vascular
Antimony	mg/kg	1.08E+01	3.10E+01	O	3E-01	Mortality, Hematological
Barium	mg/kg	3.94E+02	1.50E+04	O/I	3E-02	Kidney
Beryllium	mg/kg	1.53E+01	1.60E+02	O/I	1E-01	Gastrointestinal
Cadmium	mg/kg	1.51E+00	7.00E+01	O/D/I	2E-02	Kidney
Chromium-6 (g)	mg/kg	4.66E+02	2.35E+02	O/I	2E+00	None reported
Cobalt	mg/kg	1.25E+02	2.30E+01	O/I	5E+00	Thyroid
Copper	mg/kg	3.01E+02	3.10E+03	O	1E-01	Gastrointestinal
Lithium	mg/kg	2.47E+02	1.60E+02	O	2E+00	Kidney
Manganese	mg/kg	2.86E+02	1.80E+03	O/I	2E-01	Nervous System
Mercury	mg/kg	5.11E-02	2.30E+01	O/I	2E-03	Immune
Molybdenum	mg/kg	4.19E+01	3.90E+02	O	1E-01	Kidney
Nickel	mg/kg	2.77E+02	1.50E+03	O/I	2E-01	Body weight
Selenium	mg/kg	1.12E+01	3.90E+02	O/I	3E-02	Skin, Nails, Hair, Behavioral
Strontium	mg/kg	4.75E+02	4.70E+04	O	1E-02	Skeletal
Thallium	mg/kg	8.99E+00	7.80E-01	O	1E+01	Hair
Uranium	mg/kg	1.28E+01	2.30E+02	O/I	6E-02	Kidney, Body weight
Vanadium	mg/kg	6.22E+02	3.90E+02	O	2E+00	Hair
Zinc	mg/kg	3.39E+02	2.30E+04	O	1E-02	Hematological
Total Hazard Index:					2E+01	
Hazard Index by Target Endpoint Hazard (e)						
					2E-01	Body Weight
					2E-01	Gastrointestinal
Target Endpoint Risk Driver: Thallium					1E+01	Hair
					4E-01	Hematological
					2E-03	Immune
Target Endpoint Risk Driver: Lithium					2E+00	Kidney
					3E-01	Mortality
					3E-02	Nails, Behavioral
					2E-01	Nervous System
Target Endpoint Risk Driver: Chromium-6 (g)					2E+00	None Reported
					1E-02	Skeletal
					1E+00	Skin
Target Endpoint Risk Driver: Cobalt					5E+00	Thyroid
					1E+00	Vascular
Lead	mg/kg	5.02E+01 (k)	4.00E+02		(f)	--

Notes presented on following page.

Notes:

D - Screening level includes the dermal pathway.
I - Screening level includes the inhalation pathway.
O - Screening level includes the oral pathway.

(a) - Constituents that have screening levels for potentially carcinogenic and noncarcinogenic effects are evaluated for both.

(b) - USEPA Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012. Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm

(c) - For noncarcinogens, the hazard quotient is the 95% upper confidence limit concentration divided by the screening level, which is based on a hazard index of one. For potential carcinogens, the potential cancer risk is the 95% upper confidence limit concentration divided by the screening level and multiplied by the target risk level of $1x10^{-6}$ associated with the RSLs.

(d) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.

(e) - The total hazard index (HI) exceeds one. Therefore, constituents with individual hazard quotients greater than one are identified in bold. Constituent HI's are further refined and summed by target endpoint. Where target endpoint HIs exceed one, driving constituents are also listed. Note that the RSLs for the noncarcinogens listed in this table are driven by the oral pathway. Therefore, the target endpoint listed is based on the oral reference dose.

(f) - Lead is not included in the cumulative screen because the RSL is based on lead modeling, which does not equate to a hazard quotient. Therefore, the lead concentration is compared directly to the RSL.

(g) - It is conservatively assumed that all chromium is in hexavalent form. The screening level for hexavalent chromium was calculated based on current toxicity data available from USEPA's Integrated Risk Information System (IRIS) (see Table 1).

(h) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

(i) - The exposure point concentration is the 95% upper confidence limit on the arithmetic mean. Calculated using USEPA's ProUCL program (version 4.1.01 (USEPA, 2011)) and data from (h), unless otherwise stated.

(j) - USEPA's target risk range is $1x10^{-4}$ to $1x10^{-6}$.

(k) - The exposure point concentration used to evaluate lead per USEPA guidance is the arithmetic mean concentration.

Table 31
Cumulative Risk Screen - New Mexico Power Plant Fly Ash Product
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

AECOM

		New Mexico Power Plant Fly Ash Product (h)				
Potential Carcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Potential Carcinogenic Risk (c)**	
Arsenic	mg/kg	2.03E+01	3.90E-01	O/D/I	5E-05	
Beryllium	mg/kg	5.95E+00	1.40E+03	I	4E-09	
Cadmium	mg/kg	5.63E-01	1.80E+03	I	3E-10	
Chromium-6 (g)	mg/kg	3.93E+01	1.09E+02	I	4E-07	
Cobalt	mg/kg	1.64E+01	3.70E+02	I	4E-08	
Nickel	mg/kg	2.05E+01	1.30E+04	I	2E-09	
Total Potential Carcinogenic Risk:					5E-05	**Total within USEPA target risk range (j)**

		New Mexico Power Plant Fly Ash Product (h)				
Noncarcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Hazard Quotient (c)**	**Non-Cancer Oral Target Endpoint**
Arsenic	mg/kg	2.03E+01	2.20E+01	O/D/I	9E-01	Skin, Vascular
Antimony	mg/kg	3.41E+00	3.10E+01	O	1E-01	Mortality, Hematological
Barium	mg/kg	1.74E+03	1.50E+04	O/I	1E-01	Kidney
Beryllium	mg/kg	5.95E+00	1.60E+02	O/I	4E-02	Gastrointestinal
Cadmium	mg/kg	5.63E-01	7.00E+01	O/D/I	8E-03	Kidney
Chromium-6 (g)	mg/kg	3.93E+01	2.35E+02	O/I	2E-01	None reported
Cobalt	mg/kg	1.64E+01	2.30E+01	O/I	7E-01	Thyroid
Copper	mg/kg	6.61E+01	3.10E+03	O	2E-02	Gastrointestinal
Lithium	mg/kg	1.05E+02	1.60E+02	O	7E-01	Kidney
Manganese	mg/kg	2.02E+02	1.80E+03	O/I	1E-01	Nervous System
Mercury	mg/kg	1.68E-01	2.30E+01	O/I	7E-03	Immune
Molybdenum	mg/kg	8.83E+00	3.90E+02	O	2E-02	Kidney
Nickel	mg/kg	2.05E+01	1.50E+03	O/I	1E-02	Body weight
Selenium	mg/kg	9.65E+00	3.90E+02	O/I	2E-02	Skin, Nails, Hair, Behavioral
Strontium	mg/kg	4.15E+02	4.70E+04	O	9E-03	Skeletal
Thallium	mg/kg	1.76E+00	7.80E-01	O	2E+00	Hair
Uranium	mg/kg	1.29E+01	2.30E+02	O/I	6E-02	Kidney, Body weight
Vanadium	mg/kg	1.17E+02	3.90E+02	O	3E-01	Hair
Zinc	mg/kg	7.95E+01	2.30E+04	O	3E-03	Hematological
Total Hazard Index:					6E+00	
Hazard Index by Target Endpoint Hazard (e)						
					7E-02	Body Weight
					6E-02	Gastrointestinal
Target Endpoint Risk Driver: Thallium					3E+00	Hair
					1E-01	Hematological
					7E-03	Immune
					9E-01	Kidney
					1E-01	Mortality
					2E-02	Nails, Behavioral
					2E-01	None Reported
					1E-01	Nervous System
					9E-03	Skeletal
					9E-01	Skin
					7E-01	Thyroid
					9E-01	Vascular
Lead	mg/kg	6.19E+01 (k)	4.00E+02		(f)	--

Notes presented on following page.

Notes:
D - Screening level includes the dermal pathway.
I - Screening level includes the inhalation pathway.
O - Screening level includes the oral pathway.
(a) - Constituents that have screening levels for potentially carcinogenic and noncarcinogenic effects are evaluated for both.
(b) - USEPA Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012.
Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm
(c) - For noncarcinogens, the hazard quotient is the 95% upper confidence limit concentration divided by the screening level, which is based on a hazard index of one. For potential carcinogens, the potential cancer risk is the 95% upper confidence limit concentration divided by the screening level and multiplied by the target risk level of $1x10^{-6}$ associated with the RSLs.
(d) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.
(e) - The total hazard index (HI) exceeds one. Therefore, constituents with individual hazard quotients greater than one are identified in bold. Constituent HI's are further refined and summed by target endpoint. Where target endpoint HIs exceed one, driving constituents are also listed. Note that the RSLs for the noncarcinogens listed in this table are driven by the oral pathway. Therefore, the target endpoint listed is based on the oral reference dose.
(f) - Lead is not included in the cumulative screen because the RSL is based on lead modeling, which does not equate to a hazard quotient. Therefore, the lead concentration is compared directly to the RSL.
(g) - It is conservatively assumed that all chromium is in hexavalent form. The screening level for hexavalent chromium was calculated based on current toxicity data available from USEPA's Integrated Risk Information System (IRIS) (see Table 1).
(h) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(i) - The exposure point concentration is the 95% upper confidence limit on the arithmetic mean. Calculated using USEPA's ProUCL program (version 4.1.01 (USEPA, 2011)) and data from (h), unless otherwise stated in the Exposure Point Concentration tables.
(j) - USEPA's target risk range is $1x10^{-4}$ to $1x10^{-6}$.
(k) - The exposure point concentration used to evaluate lead per USEPA guidance is the arithmetic mean concentration.

Table 32
Cumulative Risk Screen - Ohio Power Plant Fly Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

AECOM

		Ohio Power Plant Fly Ash (h)				
Potential Carcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Potential Carcinogenic Risk (c)**	
Arsenic	mg/kg	6.63E+01	3.90E-01	O/D/I	2E-04	
Beryllium	mg/kg	1.23E+01	1.40E+03	I	9E-09	
Cadmium	mg/kg	8.21E-01	1.80E+03	I	5E-10	
Chromium-6 (g)	mg/kg	1.61E+02	1.09E+02	I	1E-06	
Cobalt	mg/kg	3.94E+01	3.70E+02	I	1E-07	
Nickel	mg/kg	1.05E+02	1.30E+04	I	8E-09	
			Total Potential Carcinogenic Risk:		2E-04	**Total above USEPA target risk range (j)**

		Ohio Power Plant Fly Ash (h)				
Noncarcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Hazard Quotient (c)**	**Non-Cancer Oral Target Endpoint**
Arsenic	mg/kg	6.63E+01	2.20E+01	O/D/I	3E+00	Skin, Vascular
Antimony	mg/kg	2.60E+00	3.10E+01	O	8E-02	Mortality, Hematological
Barium	mg/kg	5.55E+02	1.50E+04	O/I	4E-02	Kidney
Beryllium	mg/kg	1.23E+01	1.60E+02	O/I	8E-02	Gastrointestinal
Cadmium	mg/kg	8.21E-01	7.00E+01	O/D/I	1E-02	Kidney
Chromium-6 (g)	mg/kg	1.61E+02	2.35E+02	O/I	7E-01	None reported
Cobalt	mg/kg	3.94E+01	2.30E+01	O/I	2E+00	Thyroid
Copper	mg/kg	1.02E+02	3.10E+03	O	3E-02	Gastrointestinal
Lithium	mg/kg	1.21E+02	1.60E+02	O	8E-01	Kidney
Manganese	mg/kg	2.78E+02	1.80E+03	O/I	2E-01	Nervous System
Mercury	mg/kg	3.76E-02	2.30E+01	O/I	2E-03	Immune
Molybdenum	mg/kg	1.19E+01	3.90E+02	O	3E-02	Kidney
Nickel	mg/kg	1.05E+02	1.50E+03	O/I	7E-02	Body weight
Selenium	mg/kg	4.39E+00	3.90E+02	O/I	1E-02	Skin, Nails, Hair, Behavioral
Strontium	mg/kg	6.91E+02	4.70E+04	O	1E-02	Skeletal
Thallium	mg/kg	4.00E+00	7.80E-01	O	5E+00	Hair
Uranium	mg/kg	8.41E+00	2.30E+02	O/I	4E-02	Kidney, Body weight
Vanadium	mg/kg	2.71E+02	3.90E+02	O	7E-01	Hair
Zinc	mg/kg	1.22E+02	2.30E+04	O	5E-03	Hematological
			Total Hazard Index:		1E+01	
Hazard Index by Target Endpoint Hazard (e)						
					1E-01	Body Weight
					1E-01	Gastrointestinal
			Target Endpoint Risk Driver: Thallium		6E+00	Hair
					9E-02	Hematological
					2E-03	Immune
					9E-01	Kidney
					8E-02	Mortality
					1E-02	Nails, Behavioral
					2E-01	Nervous System
					7E-01	None Reported
					1E-02	Skeletal
			Target Endpoint Risk Driver: Arsenic		3E+00	Skin
			Target Endpoint Risk Driver: Cobalt		2E+00	Thyroid
			Target Endpoint Risk Driver: Arsenic		3E+00	Vascular
Lead	mg/kg	3.91E+01 (k)	4.00E+02		(f)	--

Notes presented on following page.

Notes:
D - Screening level includes the dermal pathway.
I - Screening level includes the inhalation pathway.
O - Screening level includes the oral pathway.
(a) - Constituents that have screening levels for potentially carcinogenic and noncarcinogenic effects are evaluated for both.
(b) - USEPA Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012.
Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm
(c) - For noncarcinogens, the hazard quotient is the 95% upper confidence limit concentration divided by the screening level, which is based on a hazard index of one. For potential carcinogens, the potential cancer risk is the 95% upper confidence limit concentration divided by the screening level and multiplied by the target risk level of $1x10^{-6}$ associated with the RSLs.
(d) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.
(e) - The total hazard index (HI) exceeds one. Therefore, constituents with individual hazard quotients greater than one are identified in bold. Constituent HI's are further refined and summed by target endpoint. Where target endpoint HIs exceed one, driving constituents are also listed. Note that the RSLs for the noncarcinogens listed in this table are driven by the oral pathway. Therefore, the target endpoint listed is based on the oral reference dose.
(f) - Lead is not included in the cumulative screen because the RSL is based on lead modeling, which does not equate to a hazard quotient. Therefore, the lead concentration is compared directly to the RSL.
(g) - It is conservatively assumed that all chromium is in hexavalent form. The screening level for hexavalent chromium was calculated based on current toxicity data available from USEPA's Integrated Risk Information System (IRIS) (see Table 1).
(h) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(i) - The exposure point concentration is the 95% upper confidence limit on the arithmetic mean. Calculated using USEPA's ProUCL program (version 4.1.01 (USEPA, 2011)) and data from (h), unless otherwise stated in the Exposure Point Concentration tables.
(j) - USEPA's target risk range is $1x10^{-4}$ to $1x10^{-6}$.
(k) - The exposure point concentration used to evaluate lead per USEPA guidance is the arithmetic mean concentration.

Table 33
Cumulative Risk Screen - Wyoming Power Plant Fly Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

AECOM

		Wyoming Power Plant Fly Ash (h)				
Potential Carcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Potential Carcinogenic Risk (c)**	
Arsenic	mg/kg	2.03E+01	3.90E-01	O/D/I	5E-05	
Beryllium	mg/kg	2.82E+00	1.40E+03	I	2E-09	
Cadmium	mg/kg	8.32E-01	1.80E+03	I	5E-10	
Chromium-6 (g)	mg/kg	8.85E+01	1.09E+02	I	8E-07	
Cobalt	mg/kg	4.02E+01	3.70E+02	I	1E-07	
Nickel	mg/kg	1.65E+02	1.30E+04	I	1E-08	
Total Potential Carcinogenic Risk:					5E-05	**Total within USEPA target risk range (j)**

		Wyoming Power Plant Fly Ash (h)				
Noncarcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Hazard Quotient (c)**	**Non-Cancer Oral Target Endpoint**
Arsenic	mg/kg	2.03E+01	2.20E+01	O/D/I	9E-01	Skin, Vascular
Antimony	mg/kg	1.99E+00	3.10E+01	O	6E-02	Mortality, Hematological
Barium	mg/kg	3.21E+03	1.50E+04	O/I	2E-01	Kidney
Beryllium	mg/kg	2.82E+00	1.60E+02	O/I	2E-02	Gastrointestinal
Cadmium	mg/kg	8.32E-01	7.00E+01	O/D/I	1E-02	Kidney
Chromium-6 (g)	mg/kg	8.85E+01	2.35E+02	O/I	4E-01	None reported
Cobalt	mg/kg	4.02E+01	2.30E+01	O/I	2E+00	Thyroid
Copper	mg/kg	1.55E+02	3.10E+03	O	5E-02	Gastrointestinal
Lithium	mg/kg	3.04E+01	1.60E+02	O	2E-01	Kidney
Manganese	mg/kg	2.35E+02	1.80E+03	O/I	1E-01	Nervous System
Mercury	mg/kg	9.71E-01 (l)	2.30E+01	O/I	4E-02	Immune
Molybdenum	mg/kg	5.82E+00	3.90E+02	O	1E-02	Kidney
Nickel	mg/kg	1.65E+02	1.50E+03	O/I	1E-01	Body weight
Selenium	mg/kg	1.27E+01	3.90E+02	O/I	3E-02	Skin, Nails, Hair, Behavioral
Strontium	mg/kg	2.32E+03	4.70E+04	O	5E-02	Skeletal
Thallium	mg/kg	6.24E-01	7.80E-01	O	8E-01	Hair
Uranium	mg/kg	9.27E+00	2.30E+02	O/I	4E-02	Kidney, Body weight
Vanadium	mg/kg	3.33E+02	3.90E+02	O	9E-01	Hair
Zinc	mg/kg	1.48E+02	2.30E+04	O	6E-03	Hematological
Total Hazard Index:					6E+00	
Hazard Index by Target Endpoint Hazard (e)						
					2E-01	Body Weight
					7E-02	Gastrointestinal
Target Endpoint Risk Driver: Thallium and Vanadium					2E+00	Hair
					7E-02	Hematological
					4E-02	Immune
					5E-01	Kidney
					6E-02	Mortality
					3E-02	Nails, Behavioral
					1E-01	Nervous System
					4E-01	None Reported
					5E-02	Skeletal
					1E+00	Skin
Target Endpoint Risk Driver: Cobalt					2E+00	Thyroid
					9E-01	Vascular
Lead	mg/kg	2.84E+01 (m)	4.00E+02		(f)	--

Notes presented on following page.

Notes:
D - Screening level includes the dermal pathway.
I - Screening level includes the inhalation pathway.
O - Screening level includes the oral pathway.
(a) - Constituents that have screening levels for potentially carcinogenic and noncarcinogenic effects are evaluated for both.
(b) - USEPA Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012.
Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm
(c) - For noncarcinogens, the hazard quotient is the 95% upper confidence limit concentration divided by the screening level, which is based on a hazard index of one. For potential carcinogens, the potential cancer risk is the 95% upper confidence limit concentration divided by the screening level and multiplied by the target risk level of $1x10^{-6}$ associated with the RSLs.
(d) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.
(e) - The total hazard index (HI) exceeds one. Therefore, constituents with individual hazard quotients greater than one are identified in bold. Constituent HI's are further refined and summed by target endpoint. Where target endpoint HIs exceed one, driving constituents are also listed. Note that the RSLs for the noncarcinogens listed in this table are driven by the oral pathway. Therefore, the target endpoint listed is based on the oral reference dose.
(f) - Lead is not included in the cumulative screen because the RSL is based on lead modeling, which does not equate to a hazard quotient. Therefore, the lead concentration is compared directly to the RSL.
(g) - It is conservatively assumed that all chromium is in hexavalent form. The screening level for hexavalent chromium was calculated based on current toxicity data available from USEPA's Integrated Risk Information System (IRIS) (see Table 1).
(h) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(i) - The exposure point concentration is the 95% upper confidence limit on the arithmetic mean. Calculated using USEPA's ProUCL program (version 4.1.01 (USEPA, 2011)) and data from (h), unless otherwise stated.
(j) - USEPA's target risk range is $1x10^{-4}$ to $1x10^{-6}$.
(k) - The exposure point concentration used to evaluate lead per USEPA guidance is the arithmetic mean concentration.
(l) - The recommended UCL exceeded the maximum detected concentration. Therefore, the maximum detected concentration was used.
(m) - The exposure point concentration used to evaluate lead per USEPA guidance is the arithmetic mean concentration.

Table 34
Cumulative Risk Screen - New Mexico Power Plant Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

AECOM

		New Mexico Power Plant Bottom Ash (h)					
Potential Carcinogens (a)	**Units**	**Exposure Point Concentration (i)**		**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Potential Carcinogenic Risk (c)**	
Arsenic	mg/kg	6.96E+00		3.90E-01	O/D/I	2E-05	
Beryllium	mg/kg	4.39E+00		1.40E+03	I	3E-09	
Chromium-6 (g)	mg/kg	2.39E+01		1.09E+02	I	2E-07	
Cobalt	mg/kg	9.00E+00		3.70E+02	I	2E-08	
Nickel	mg/kg	3.81E+01		1.30E+04	I	3E-09	
Total Potential Carcinogenic Risk:						2E-05	**Total within USEPA target risk range (j)**

		New Mexico Power Plant Bottom Ash (h)					
Noncarcinogens (a)	**Units**	**Exposure Point Concentration (i)**		**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Hazard Quotient (c)**	**Non-Cancer Oral Target Endpoint**
Arsenic	mg/kg	6.96E+00		2.20E+01	O/D/I	3E-01	Skin, Vascular
Antimony	mg/kg	6.92E-01		3.10E+01	O	2E-02	Mortality, Hematological
Barium	mg/kg	1.53E+03		1.50E+04	O/I	1E-01	Kidney
Beryllium	mg/kg	4.39E+00		1.60E+02	O/I	3E-02	Gastrointestinal
Chromium-6 (g)	mg/kg	2.39E+01		2.35E+02	O/I	1E-01	None reported
Cobalt	mg/kg	9.00E+00		2.30E+01	O/I	4E-01	Thyroid
Copper	mg/kg	4.36E+01		3.10E+03	O	1E-02	Gastrointestinal
Lithium	mg/kg	1.03E+02		1.60E+02	O	6E-01	Kidney
Manganese	mg/kg	2.53E+02		1.80E+03	O/I	1E-01	Nervous System
Mercury	mg/kg	1.55E-01	(l)	2.30E+01	O/I	7E-03	Immune
Molybdenum	mg/kg	2.87E+00		3.90E+02	O	7E-03	Kidney
Nickel	mg/kg	3.81E+01		1.50E+03	O/I	3E-02	Body weight
Selenium	mg/kg	2.71E-01		3.90E+02	O/I	7E-04	Skin, Nails, Hair, Behavioral
Strontium	mg/kg	3.45E+02		4.70E+04	O	7E-03	Skeletal
Thallium	mg/kg	7.27E-01		7.80E-01	O	9E-01	Hair
Uranium	mg/kg	9.90E+00		2.30E+02	O/I	4E-02	Kidney, Body weight
Vanadium	mg/kg	8.08E+01		3.90E+02	O	2E-01	Hair
Zinc	mg/kg	3.48E+01		2.30E+04	O	2E-03	Hematological
Total Hazard Index:						3E+00	
Hazard Index by Target Endpoint Hazard (e)							
						7E-02	Body Weight
						4E-02	Gastrointestinal
						1E+00	Hair
						2E-02	Hematological
						7E-03	Immune
						8E-01	Kidney
						2E-02	Mortality
						7E-04	Nails, Behavioral
						1E-01	Nervous System
						1E-01	None Reported
						7E-03	Skeletal
						3E-01	Skin
						4E-01	Thyroid
						3E-01	Vascular
Lead	mg/kg	1.92E+01	(k)	4.00E+02		(f)	--

Notes presented on following page.

Notes:
D - Screening level includes the dermal pathway.
I - Screening level includes the inhalation pathway.
O - Screening level includes the oral pathway.
(a) - Constituents that have screening levels for potentially carcinogenic and noncarcinogenic effects are evaluated for both.
(b) - USEPA Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012.
Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm
(c) - For noncarcinogens, the hazard quotient is the 95% upper confidence limit concentration divided by the screening level, which is based on a hazard index of one. For potential carcinogens, the potential cancer risk is the 95% upper confidence limit concentration divided by the screening level and multiplied by the target risk level of $1x10^{-6}$ associated with the RSLs.
(d) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.
(e) - The total hazard index (HI) exceeds one. Therefore, constituents with individual hazard quotients greater than one are identified in bold. Constituent HI's are further refined and summed by target endpoint. Where target endpoint HIs exceed one, driving constituents are also listed. Note that the RSLs for the noncarcinogens listed in this table are driven by the oral pathway. Therefore, the target endpoint listed is based on the oral reference dose.
(f) - Lead is not included in the cumulative screen because the RSL is based on lead modeling, which does not equate to a hazard quotient. Therefore, the lead concentration is compared directly to the RSL.
(g) - It is conservatively assumed that all chromium is in hexavalent form. The screening level for hexavalent chromium was calculated based on current toxicity data available from USEPA's Integrated Risk Information System (IRIS) (see Table 1).
(h) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(i) - The exposure point concentration is the 95% upper confidence limit on the arithmetic mean. Calculated using USEPA's ProUCL program (version 4.1.01 (USEPA, 2011)) and data from (h), unless otherwise stated.
(j) - USEPA's target risk range is $1x10^{-4}$ to $1x10^{-6}$.
(k) - The exposure point concentration used to evaluate lead per USEPA guidance is the arithmetic mean concentration.
(l) - The exposure point concentraiton is equal to the maximum detected concentration due to the limited frequency of detection.

Table 35
Cumulative Risk Screen - Ohio Power Plant Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

AECOM

		Ohio Power Plant Bottom Ash (h)				
Potential Carcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Potential Carcinogenic Risk (c)**	
Arsenic	mg/kg	7.28E+00	3.90E-01	O/D/I	2E-05	
Beryllium	mg/kg	9.39E+00	1.40E+03	I	7E-09	
Cadmium	mg/kg	1.31E-01	1.80E+03	I	7E-11	
Chromium-6 (g)	mg/kg	3.97E+02	1.09E+02	I	4E-06	
Cobalt	mg/kg	3.66E+01	3.70E+02	I	1E-07	
Nickel	mg/kg	2.11E+02	1.30E+04	I	2E-08	
Total Potential Carcinogenic Risk:					2E-05	**Total within USEPA target risk range (j)**

		Ohio Power Plant Bottom Ash (h)				
Noncarcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Hazard Quotient (c)**	**Non-Cancer Oral Target Endpoint**
Arsenic	mg/kg	7.28E+00	2.20E+01	O/D/I	3E-01	Skin, Vascular
Antimony	mg/kg	1.60E+00	3.10E+01	O	5E-02	Mortality, Hematological
Barium	mg/kg	4.97E+02	1.50E+04	O/I	3E-02	Kidney
Beryllium	mg/kg	9.39E+00	1.60E+02	O/I	6E-02	Gastrointestinal
Cadmium	mg/kg	1.31E-01	7.00E+01	O/D/I	2E-03	Kidney
Chromium-6 (g)	mg/kg	3.97E+02	2.35E+02	O/I	2E+00	None reported
Cobalt	mg/kg	3.66E+01	2.30E+01	O/I	2E+00	Thyroid
Copper	mg/kg	6.32E+01	3.10E+03	O	2E-02	Gastrointestinal
Lithium	mg/kg	9.43E+01	1.60E+02	O	6E-01	Kidney
Manganese	mg/kg	3.28E+02	1.80E+03	O/I	2E-01	Nervous System
Mercury	mg/kg	2.07E-02 (l)	2.30E+01	O/I	9E-04	Immune
Molybdenum	mg/kg	8.60E+00	3.90E+02	O	2E-02	Kidney
Nickel	mg/kg	2.11E+02	1.50E+03	O/I	1E-01	Body weight
Selenium	mg/kg	2.83E-01	3.90E+02	O/I	7E-04	Skin, Nails, Hair, Behavioral
Strontium	mg/kg	6.14E+02	4.70E+04	O	1E-02	Skeletal
Thallium	mg/kg	5.79E-01	7.80E-01	O	7E-01	Hair
Uranium	mg/kg	5.95E+00	2.30E+02	O/I	3E-02	Kidney, Body weight
Vanadium	mg/kg	2.13E+02	3.90E+02	O	5E-01	Hair
Zinc	mg/kg	6.30E+01	2.30E+04	O	3E-03	Hematological
Total Hazard Index:					6E+00	
Hazard Index by Target Endpoint Hazard (e)						
					2E-01	Body Weight
					8E-02	Gastrointestinal
					1E+00	Hair
					5E-02	Hematological
					9E-04	Immune
					7E-01	Kidney
					5E-02	Mortality
					7E-04	Nails, Behavioral
					2E-01	Nervous System
Target Endpoint Risk Driver: Chromium-6 (g)					2E+00	None Reported
					1E-02	Skeletal
					3E-01	Skin
Target Endpoint Risk Driver: Cobalt					2E+00	Thyroid
					3E-01	Vascular
Lead	mg/kg	1.75E+01 (k)	4.00E+02		(f)	--

Notes presented on following page.

Notes:

D - Screening level includes the dermal pathway.
I - Screening level includes the inhalation pathway.
O - Screening level includes the oral pathway.

(a) - Constituents that have screening levels for potentially carcinogenic and noncarcinogenic effects are evaluated for both.

(b) - USEPA Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012. Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm

(c) - For noncarcinogens, the hazard quotient is the 95% upper confidence limit concentration divided by the screening level, which is based on a hazard index of one. For potential carcinogens, the potential cancer risk is the 95% upper confidence limit concentration divided by the screening level and multiplied by the target risk level of $1x10^{-6}$ associated with the RSLs.

(d) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.

(e) - The total hazard index (HI) exceeds one. Therefore, constituents with individual hazard quotients greater than one are identified in bold. Constituent HI's are further refined and summed by target endpoint. Where target endpoint HIs exceed one, driving constituents are also listed. Note that the RSLs for the noncarcinogens listed in this table are driven by the oral pathway. Therefore, the target endpoint listed is based on the oral reference dose.

(f) - Lead is not included in the cumulative screen because the RSL is based on lead modeling, which does not equate to a hazard quotient. Therefore, the lead concentration is compared directly to the RSL.

(g) - It is conservatively assumed that all chromium is in hexavalent form. The screening level for hexavalent chromium was calculated based on current toxicity data available from USEPA's Integrated Risk Information System (IRIS) (see Table 1).

(h) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

(i) - The exposure point concentration is the 95% upper confidence limit on the arithmetic mean. Calculated using USEPA's ProUCL program (version 4.1.01 (USEPA, 2011)) and data from (h), unless otherwise stated.

(j) - USEPA's target risk range is $1x10^{-4}$ to $1x10^{-6}$.

(k) - The exposure point concentration used to evaluate lead per USEPA guidance is the arithmetic mean concentration.

(l) - The exposure point concentraiton is equal to the maximum detected concentration due to the limited frequency of detection.

Table 36
Cumulative Risk Screen - Wyoming Power Plant Bottom Ash
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

AECOM

		Wyoming Power Plant Bottom Ash (h)				
Potential Carcinogens (a)	**Units**	**Exposure Point Concentration (i)**	**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Potential Carcinogenic Risk (c)**	
Arsenic	mg/kg	6.85E+00	3.90E-01	O/D/I	2E-05	
Beryllium	mg/kg	3.49E+00	1.40E+03	I	2E-09	
Cadmium	mg/kg	2.95E-01	1.80E+03	I	2E-10	
Chromium-6 (g)	mg/kg	8.05E+01	1.09E+02	I	7E-07	
Cobalt	mg/kg	4.83E+01	3.70E+02	I	1E-07	
Nickel	mg/kg	1.18E+02	1.30E+04	I	9E-09	
Total Potential Carcinogenic Risk:					2E-05	**Total within USEPA target risk range (j)**

		Wyoming Power Plant Bottom Ash (h)					
Noncarcinogens (a)	**Units**	**Exposure Point Concentration (i)**		**Residential Soil Regional Screening Level (b) (d)**	**Basis of Screening Level**	**Hazard Quotient (c)**	**Non-Cancer Oral Target Endpoint**
Arsenic	mg/kg	6.85E+00		2.20E+01	O/D/I	3E-01	Skin, Vascular
Antimony	mg/kg	8.01E-01		3.10E+01	O	3E-02	Mortality, Hematological
Barium	mg/kg	2.83E+03		1.50E+04	O/I	2E-01	Kidney
Beryllium	mg/kg	3.49E+00		1.60E+02	O/I	2E-02	Gastrointestinal
Cadmium	mg/kg	2.95E-01		7.00E+01	O/D/I	4E-03	Kidney
Chromium-6 (g)	mg/kg	8.05E+01		2.35E+02	O/I	3E-01	None reported
Cobalt	mg/kg	4.83E+01		2.30E+01	O/I	2E+00	Thyroid
Copper	mg/kg	1.35E+02		3.10E+03	O	4E-02	Gastrointestinal
Lithium	mg/kg	3.62E+01		1.60E+02	O	2E-01	Kidney
Manganese	mg/kg	2.69E+02		1.80E+03	O/I	1E-01	Nervous System
Mercury	mg/kg	4.24E-02		2.30E+01	O/I	2E-03	Immune
Molybdenum	mg/kg	3.24E+00		3.90E+02	O	8E-03	Kidney
Nickel	mg/kg	1.18E+02		1.50E+03	O/I	8E-02	Body weight
Selenium	mg/kg	7.50E-01		3.90E+02	O/I	2E-03	Skin, Nails, Hair, Behavioral
Strontium	mg/kg	2.58E+03		4.70E+04	O	5E-02	Skeletal
Thallium	mg/kg	1.88E-01		7.80E-01	O	2E-01	Hair
Uranium	mg/kg	9.14E+00		2.30E+02	O/I	4E-02	Kidney, Body weight
Vanadium	mg/kg	4.67E+02		3.90E+02	O	1E+00	Hair
Zinc	mg/kg	9.89E+01		2.30E+04	O	4E-03	Hematological
Total Hazard Index:						5E+00	
Hazard Index by Target Endpoint Hazard (e)							
						1E-01	Body Weight
						7E-02	Gastrointestinal
						1E+00	Hair
						3E-02	Hematological
						2E-03	Immune
						5E-01	Kidney
						3E-02	Mortality
						2E-03	Nails, Behavioral
						1E-01	Nervous System
						3E-01	None Reported
						5E-02	Skeletal
						3E-01	Skin
Target Endpoint Risk Driver: Cobalt						2E+00	Thyroid
						3E-01	Vascular
Lead	mg/kg	9.27E+00	(k)	4.00E+02		(f)	--

Notes presented on following page.

Notes:
D - Screening level includes the dermal pathway.
I - Screening level includes the inhalation pathway.
O - Screening level includes the oral pathway.
(a) - Constituents that have screening levels for potentially carcinogenic and noncarcinogenic effects are evaluated for both.
(b) - USEPA Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites. May 2012.
Values for residential soil. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/index.htm
(c) - For noncarcinogens, the hazard quotient is the 95% upper confidence limit concentration divided by the screening level, which is based on a hazard index of one. For potential carcinogens, the potential cancer risk is the 95% upper confidence limit concentration divided by the screening level and multiplied by the target risk level of 1×10^{-6} associated with the RSLs.
(d) - Residential RSLs are based on exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.
(e) - The total hazard index (HI) exceeds one. Therefore, constituents with individual hazard quotients greater than one are identified in bold. Constituent HI's are further refined and summed by target endpoint. Where target endpoint HIs exceed one, driving constituents are also listed. Note that the RSLs for the noncarcinogens listed in this table are driven by the oral pathway. Therefore, the target endpoint listed is based on the oral reference dose.
(f) - Lead is not included in the cumulative screen because the RSL is based on lead modeling, which does not equate to a hazard quotient. Therefore, the lead concentration is compared directly to the RSL.
(g) - It is conservatively assumed that all chromium is in hexavalent form. The screening level for hexavalent chromium was calculated based on current IRIS toxicity data (see Table 1).
(h) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/
(i) - The exposure point concentration is the 95% upper confidence limit on the arithmetic mean. Calculated using USEPA's ProUCL program (version 4.1.01 (USEPA, 2011)) and data from (h), unless otherwise stated.
(j) - USEPA's target risk range is 1×10^{-4} to 1×10^{-6}.
(k) - The exposure point concentration used to evaluate lead per USEPA guidance is the arithmetic mean concentration.

Table 37
Summary of Potential Risks and Hazard Indices
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Source of Analytical Data Used in Evaluation (a)				Cumulative Risk-Based Screening Results Assuming a Scenario Where a Residential Yard is Comprised Entirely of Coal Ash (b)			
Power Plant Location	**Coal Used**	**Coal Ash Included in Risk-Based Evaluation**	**Sample Size**	**Potential Cancer Risk**	**Potential Cancer Risk Drivers**	**Target Endpoint Specific Hazard Index (>1)**	**Potential Target Endpoint Risk Drivers**
Alaska	Nenana Coal Province	Fly Ash/Bottom Ash	19	6E-05	None	2E+00	Thallium (hair)
						2E+00	Chromium-6 (none reported) (c)
Indiana	Illinois	Fly Ash	13	8E-05	None	2E+00	Lithium (kidney)
						2E+00	Chromium-6 (none reported) (c)
						1E+01	Thallium (hair)
						5E+00	Colbalt (thyroid)
New Mexico	San Juan	Fly Ash (Product)	16	5E-05	None	3E+00	Thallium (hair)
		Bottom Ash	18	2E-05	None	None	None
Ohio	Appalachian	Fly Ash	13	2E-04	Arsenic	3E+00	Arsenic (skin, vascular)
						2E+00	Cobalt (thyroid)
						6E+00	Thallium (hair)
		Bottom Ash	15	2E-05	None	2E+00	Chromium-6 (none reported) (c)
						2E+00	Cobalt (thyroid)
Wyoming	Powder River	Fly Ash	15	5E-05	None	2E+00	Cobalt (thyroid)
						2E+00	Thallium and vanadium (hair)
		Bottom Ash	15	2E-05	None	2E+00	Cobalt (thyroid)

Notes:

USEPA - United States Environmental Protection Agency.

(a) - Data from USGS. 2011. Geochemical Database of Feed Coal and Coal Combustion Products (CCPs) from Five Power Plants in the United States. Data Series 635. Available at: http://pubs.usgs.gov/ds/635/

(b) - Risk based screening conducted using conservative default assumptions used by the USEPA. Assumes residential exposure via incidental ingestion, dermal contact, and inhalation for 350 days per year for 30 years. For the ingestion component, it is assumed that a 15 kg child incidentally ingests 200 mg soil per day for 6 years and a 70 kg adult incidentally ingests 100 mg soil per day for 24 years.

(c) - It is conservatively assumed that all chromium is in hexavalent form. The screening level for hexavalent chromium was calculated based on current toxicity data available from USEPA's Integrated Risk Information System (IRIS).

Table 38

Evaluation of Chromium - Total and Hexavalent

Coal Ash Material Safety - A Health Risk-Based Evaluation

American Coal Ash Association

State	Coal Ash	Units	Total Chromium (a)	Calculated Hexavalent Chromium at 5% Total (b) (d)
Alaska	Fly Ash/Bottom Ash	mg/kg	487.6	1.2 (c)
Indiana	Fly Ash	mg/kg	466.1	23.3
New Mexico	Fly Ash (Product)	mg/kg	39.33	2.0
	Bottom Ash	mg/kg	23.93	1.2
Ohio	Fly Ash	mg/kg	160.8	8.0
	Bottom Ash	mg/kg	397.4	19.9
Wyoming	Fly Ash	mg/kg	88.46	4.4
	Bottom Ash	mg/kg	80.5	4.0

Notes:

(a) - Total Chromium as the 95% upper confidence limit on the arithmetic mean, as presented on Tables 19-26 of this report.

(b) - Hexavalent chromium assumed to be 5% of total chromium, the upper end of the range reported for US coal ashes by Huggins et al. (1999).

(c) - Hexavalent chromium reported to be 0.25% of total chromium for the Alaska Power Plant.

(d) - The Regional Screening Level (USEPA, 2012a) is 29 mg/kg at a 10^{-4} target risk level using dose-response information not present on the USEPA Integrated Risk Information System; and 10,900 mg/kg using current dose-response data from the Integrated Risk Information System (see Table 17 of this report); the noncancer hexavalent chromium RSLs are 230 mg/kg and 235 mg/kg, respectively.

Figures

Figure 1
ACAA CCP Production and Use Survey Report
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

ACAA
15200 E. Girard Ave., Ste 3050
Aurora, CO 80014

Phone: 720-870-7897
Fax: 720-870-7889
Internet: www.ACAA-USA.org
Email: info@acaa-usa.org

2010 Coal Combustion Product (CCP) Production & Use Survey Report

Beneficial Utilization versus Production Totals (Short Tons)

CCP Categories	Fly Ash**	Bottom Ash**	Boiler Slag*	FGD Gypsum**	FGD Material Wet Scrubbers*	FGD Material Dry Scrubbers*	FGD Other*	FBC Ash*	CCP Production / Utilization Totals
2010 Total CCPs Produced by Category	67,700,000	17,800,000	2,332,944	22,000,000	8,670,814	1,405,952	3,740	10,267,914	130,181,364
2010 Total CCPs Used by Category	25,723,217	7,541,732	1,418,996	10,713,138	624,223	584,112	0	8,732,008	55,337,426
1. Concrete/Concrete Products /Grout	11,016,097	615,332	0	21,045	0	16,847	0	0	11,669,321
2. Blended Cement/ Raw Feed for Clinker	2,045,797	949,183	3,000	1,135,211	0	0	0	0	4,133,191
3. Flowable Fill	135,321	52,414	0	0	0	13,998	0	0	201,733
4. Structural Fills/Embankments	4,675,992	3,124,549	78,647	454,430	424,581	358,019	0	0	9,116,218
5. Road Base/Sub-base	242,952	715,357	3,128	0	3,018	0	0	0	964,455
6. Soil Modification/Stabilization	785,552	162,065	0	0	0	19,189	0	0	966,806
7. Snow and Ice Control	0	549,520	41,194	0	0	0	0	0	590,714
8. Blasting Grit/Roofing Granules	86,484	19,914	1,257,571	0	0	0	0	0	1,363,969
9. Mining Applications	2,399,837	528,881	0	835,536	186,624	112,373	0	8,660,408	12,723,659
10. Gypsum Panel Products	109	0	0	7,661,527	0	0	0	0	7,661,636
11. Waste Stabilization/Solidification	3,258,825	41,233	0	0	0	39,283	0	71,600	3,410,941
12. Agriculture	22,220	4,674	0	481,827	0	0	0	0	508,721
13. Aggregate	6,726	555,031	27,155	0	0	0	0	0	588,912
14. Miscellaneous/Other	1,047,305	223,579	8,301	123,562	10,000	24,403	0	0	1,437,150

Summary Utilization to Production Rate

CCP Categories	Fly Ash	Bottom Ash	Boiler Slag	FGD Gypsum	FGD Material Wet Scrubbers	FGD Material Dry Scrubbers	FGD Other	FBC Ash	CCP Utilization Total**
2010 Totals by CCP Type/Application	25,723,217	7,541,732	1,418,996	10,713,138	624,223	584,112	0	8,732,008	**55,337,426**
Category Use to Production Rate (%)***	37.90%	42.30%	60.80%	48.60%	7.10%	41.50%		85.00%	**42.50%**

2010 Cenospheres Sold (Pounds)	15,485,980

ACAA received survey data representing 231,379 MegaWatts Name Plate capacity of the total industry-wide approximate 327,983 capacity (i.e., 69.7%) or approximatley 67% of the coal-fueled electric utility generation as reported by EIA

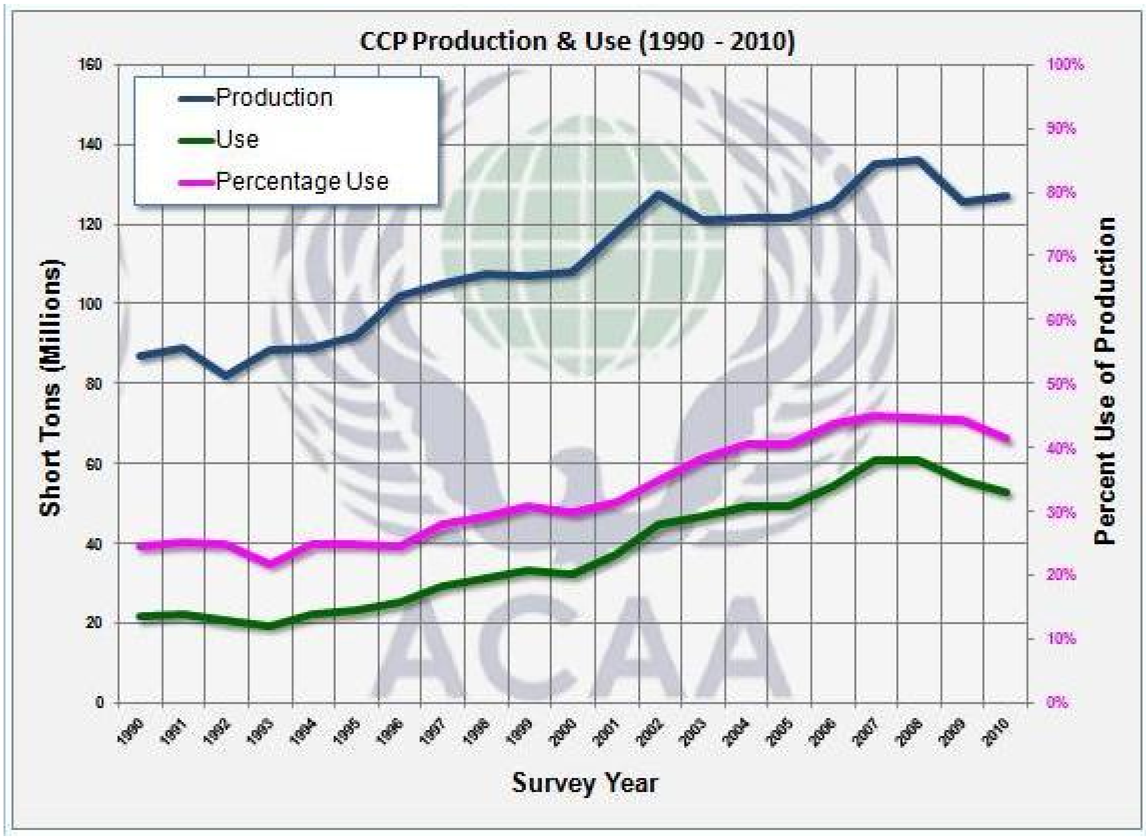
* These are actual tonnages reported by utilities responding and **do not reflect estimates for utilities that did not respond** this year.

FINAL - 102011

**These numbers are derived from previous, current and applicable industry-wide available data, including Energy Information Administration (EIA) Reports 923 and 860 and other outside sources.

***Utilization estimates are based on actual tons reported and on **extrapolated estimates for fly ash, bottom ash, and FGD gypsum**;

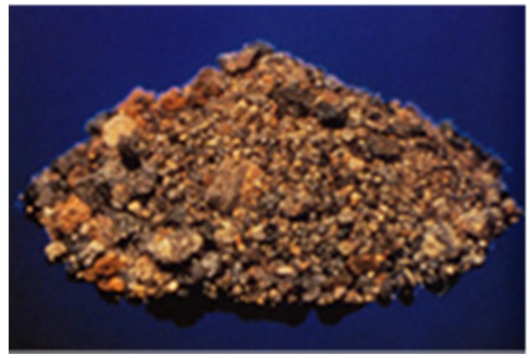
Figure 2
Trends in CCP Production & Use
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association



Source: ACAA, 2011b. Available at:
http://www.acaa-usa.org/associations/8003/files/121411_News_Release_CCP_Production_and_Use_Survey_2010.pdf

Figure 3
Coal Combustion Products
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Fly Ash



Bottom Ash

Boiler Slag

FGD Gypsum

Figure 4
Concentrations in Context
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Why are they called trace elements?

They are present in concentrations of milligram per kilogram (mg/kg) in soils and in CCPs, equivalent to:

One part per million (ppm), or

1 penny in a stack of $10,000

1 second in 11.5 days

1 inch in 15.8 miles

This is roughly the distance from the Capitol Building to a location between Tyson's Corner, VA and Vienna, VA.

Source: Google Maps

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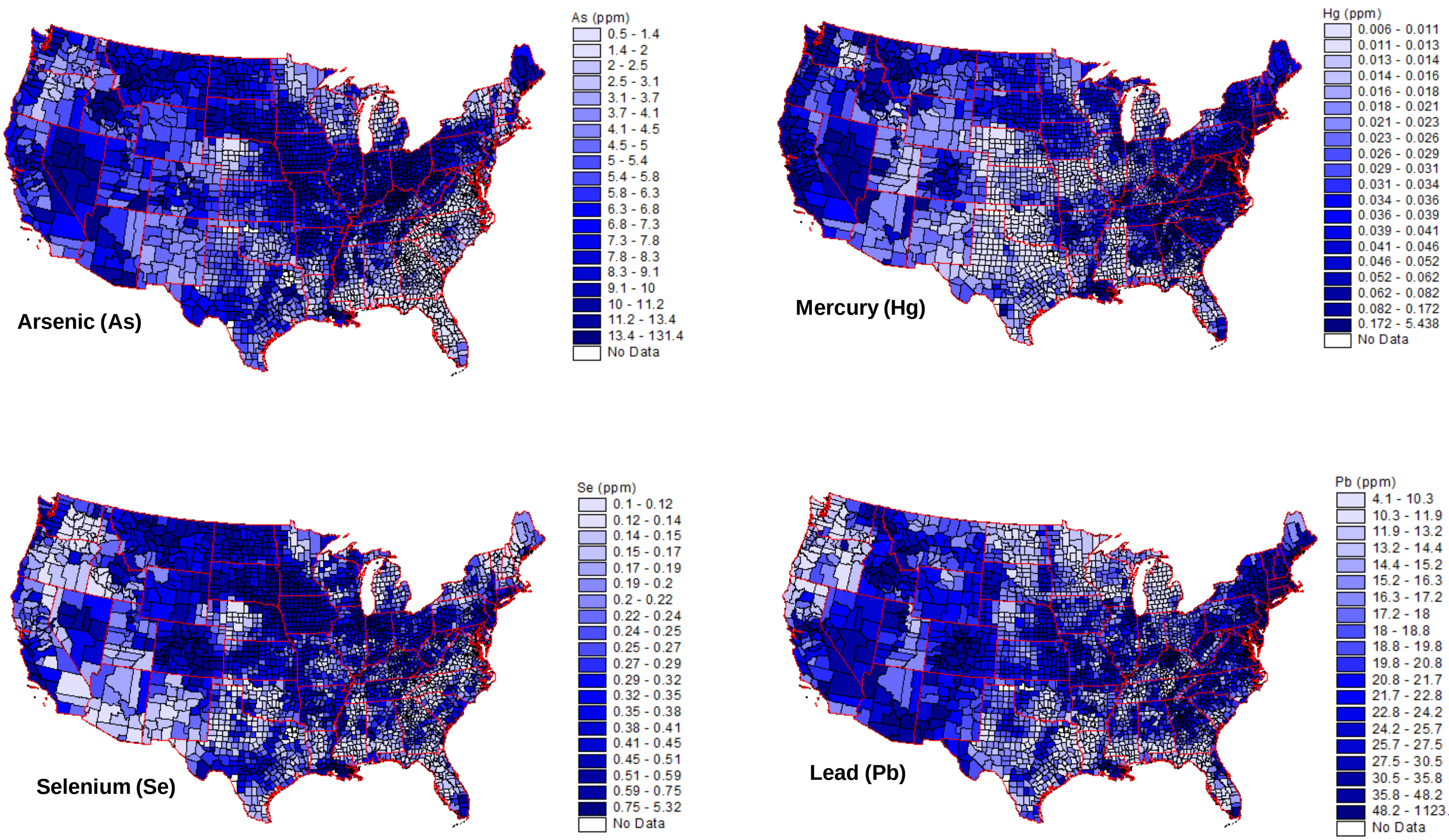
Figure 5
USGS Maps of Background Soils
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association



Notes: ppm = parts per million = mg/kg = milligram of constituent per kilogram of soil

Source: USGS. National Geochemical Survey. http://mrdata.usgs.gov/geochem/doc/averages/countydata.htm

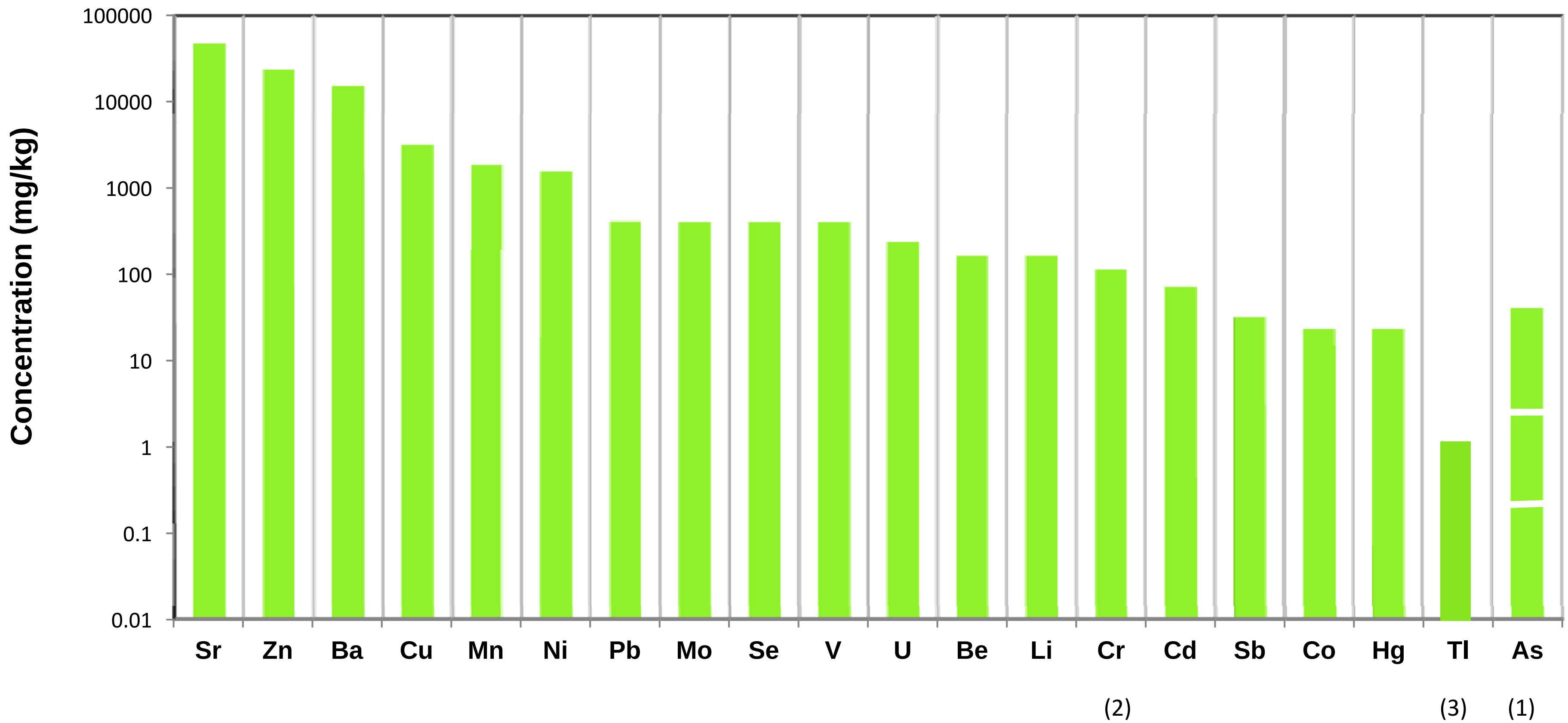
Figure 6
Chemical Symbols
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

Sorted Alphabetically by Element Name	Sorted Alphabetically by Chemical Symbol	Sorted in the Order Presented on Graphs - By Descending RSL Concentration
Sb – Antimony	As – Arsenic	Sr – Strontium
As – Arsenic	Ba – Barium	Zn – Zinc
Ba – Barium	Be – Beryllium	Ba – Barium
Be – Beryllium	Cd – Cadmium	Cu – Copper
Cd – Cadmium	Co – Cobalt	Mn – Manganese
Cr – Chromium	Cr – Chromium	Ni – Nickel
Co – Cobalt	Cu – Copper	Pb – Lead
Cu – Copper	Hg – Mercury	Mo – Molybdenum
Pb – Lead	Li – Lithium	Se – Selenium
Li – Lithium	Mn – Manganese	V – Vanadium
Mn – Manganese	Mo – Molybdenum	U – Uranium
Hg – Mercury	Ni – Nickel	U – Uranium
Mo – Molybdenum	Pb – Lead	Li – Lithium
Ni – Nickel	Sb – Antimony	Cr – Chromium
Se – Selenium	Se – Selenium	Cd – Cadmium
Sr – Strontium	Sr – Strontium	Sb – Antimony
Tl – Thallium	Tl – Thallium	Co – Cobalt
U – Uranium	U – Uranium	Hg – Mercury
V – Vanadium	V – Vanadium	Tl – Thallium
Zn – Zinc	Zn – Zinc	As – Arsenic

Note:
RSL - Regional Screening Level - for residential soil.

Figure 7
Coal Ash Material Safety - A Health Risk-Based Evaluation
American Coal Ash Association

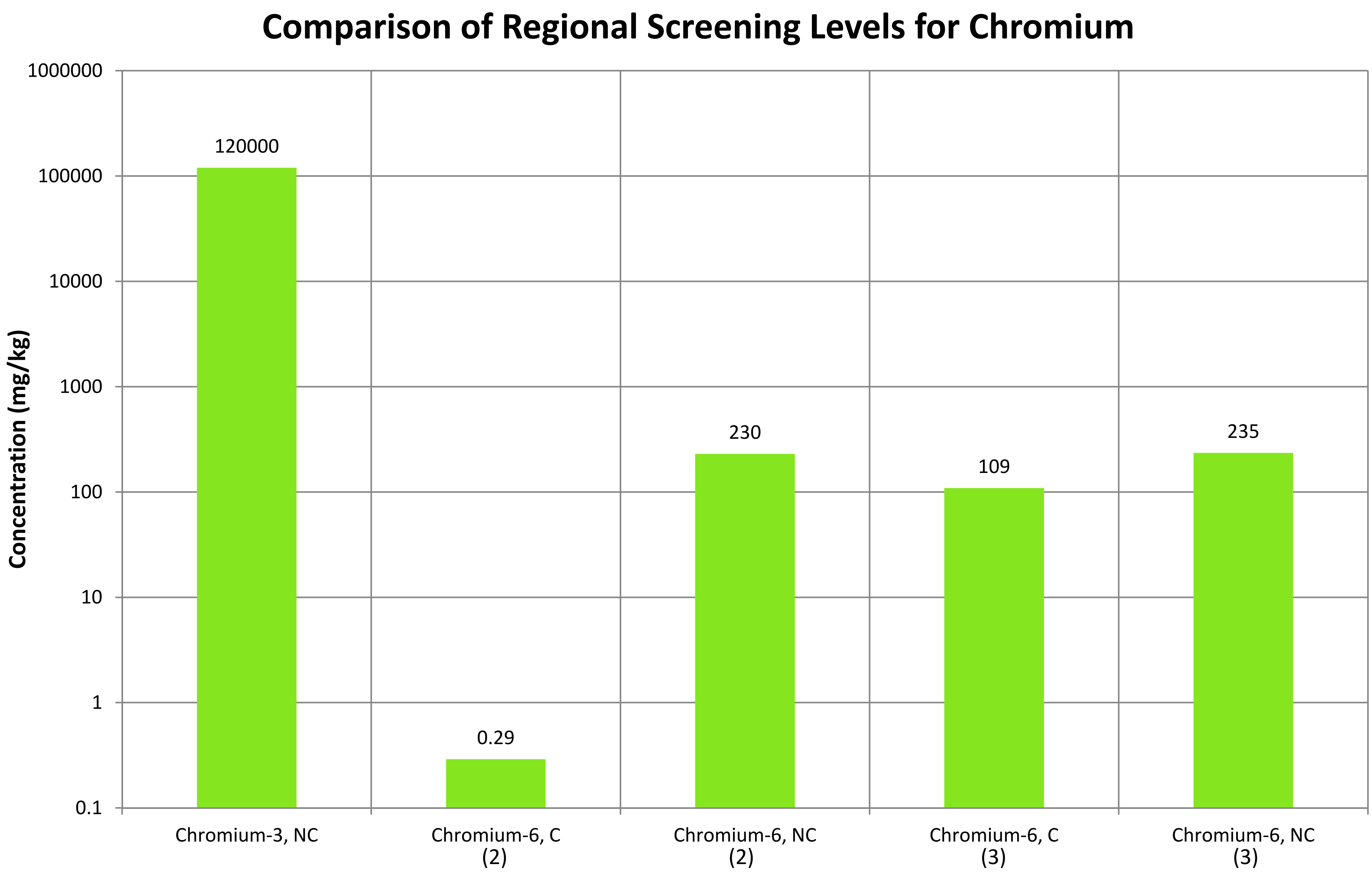
USEPA Regional Screening Levels for Residential Soils



■ Top of bar corresponds to the USEPA Regional Screening Level (RSL) - Residential Soil (May 2012)

http://www.epa.gov/region9/superfund//prg/index.html

Notes:
(1) Arsenic RSLs for target risk level of 10^{-4} (top of green bar), 10^{-5} (middle white bar), 10^{-6} (lower white bar.
(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.
(3) The RSL for thallium is identified by USEPA as a "provisional value" of "limited usefulness" that was developed for information purposes although USEPA states "it is inappropriate to derive a provisional subchronic or chronic [toxicity value] for thallium" [http://hhpprtv.ornl.gov/issue_papers/ThalliumandCompounds.pdf]



Notes:

1. N = Noncarcinogenic. C = Carcinogenic
2. RSLs for hexavalent chromium. Based on toxcity data not presented in the Integrated Risk Information System.
3. Alternative screening level calculated for hexavalent chromium using RSL calculator and current dose-response data from the Integrated Risk Information System.

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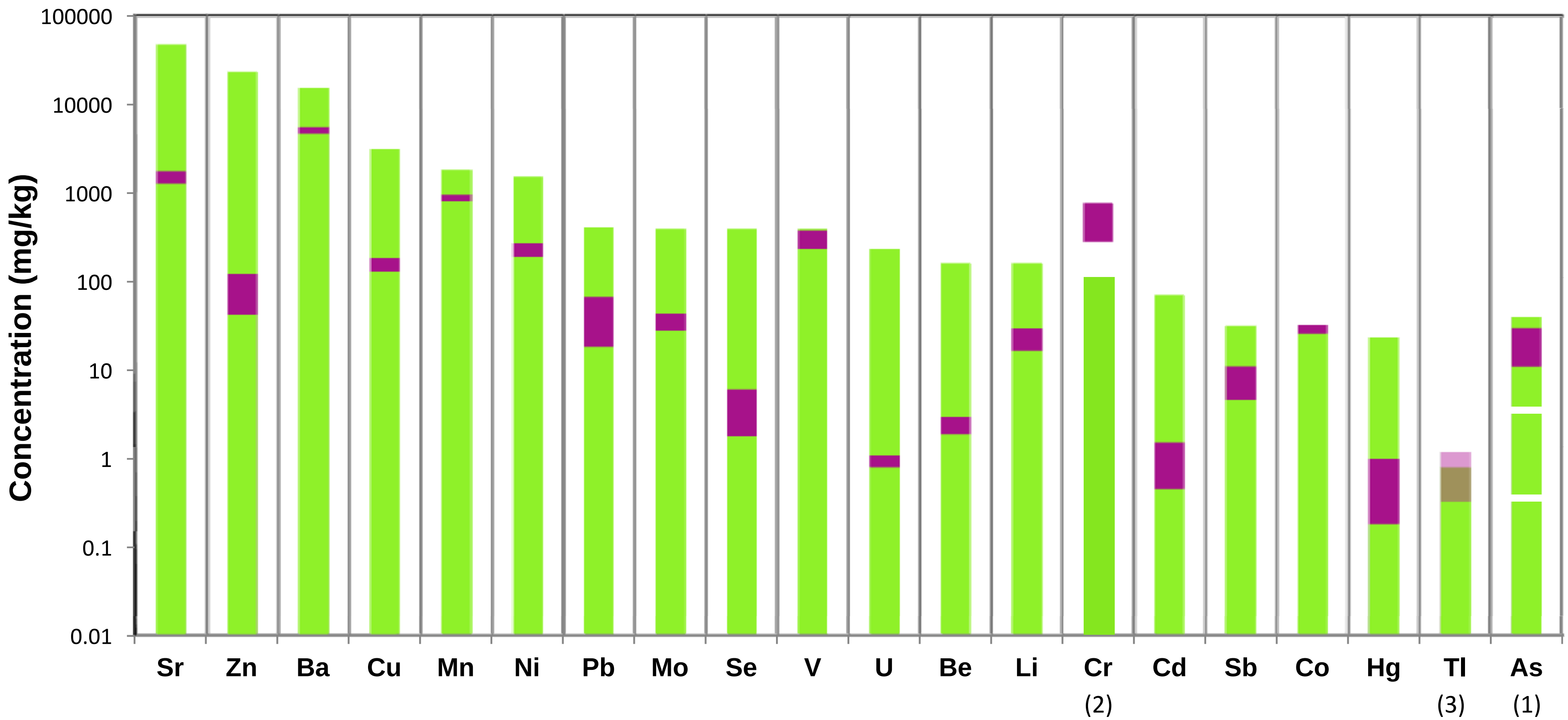
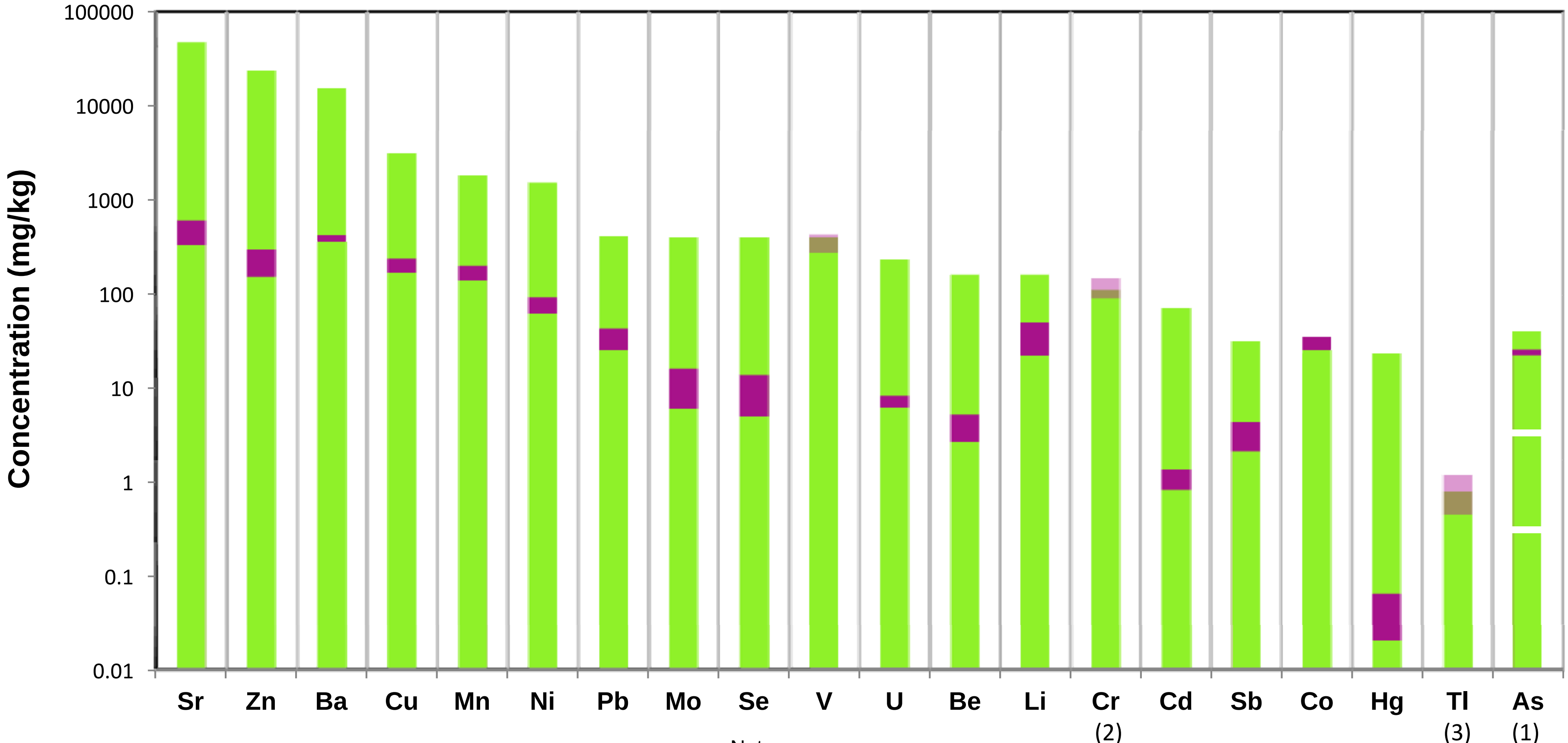
Comparison of USGS Database Constituent Concentrations in Fly Ash at the Alaska Coal Power Plant to the USEPA Regional Screening Levels for Residential Soils



- Concentration Range (10th - 90th Percentile) in Alaska Fly Ash/Bottom Ash; USGS 2011 http://pubs.usgs.gov/ds/635/
- Top of bar corresponds to the USEPA Regional Screening Level (RSL) - Residential Soil (May 2012) http://www.epa.gov/region9/superfund//prg/index.html

Notes:
(1) Arsenic RSLs for target risk level of 10^{-4} (top of green bar), 10^{-5} (middle white bar), 10^{-6} (lower white bar.
(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.
(3) The RSL for thallium is identified by USEPA as a "provisional value" of "limited usefulness" that was developed for information purposes although USEPA states "it is inappropriate to derive a provisional subchronic or chronic [toxicity value] for thallium" [http://hhpprtv.ornl.gov/issue_papers/ThalliumandCompounds.pdf]

Comparison of USGS Database Constituent Concentrations in All Fly Ash at the Indiana Coal Power Plant to the USEPA Regional Screening Levels for Residential Soils



■ Concentration Range (10th - 90th Percentile) in Indiana All Fly Ash; USGS 2011

http://pubs.usgs.gov/ds/635/

■ Top of bar corresponds to the USEPA Regional Screening Level (RSL) - Residential Soil (May 2012)

http://www.epa.gov/region9/superfund//prg/index.html

Notes:

(1) Arsenic RSLs for target risk level of 10^{-4} (top of green bar), 10^{-5} (middle white bar), 10^{-6} (lower white bar.

(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.

(3) The RSL for thallium is identified by USEPA as a "provisional value" of "limited usefulness" that was developed for information purposes although USEPA states "it is inappropriate to derive a provisional subchronic or chronic [toxicity value] for thallium" [http://hhpprtv.ornl.gov/issue_papers/ThalliumandCompounds.pdf]

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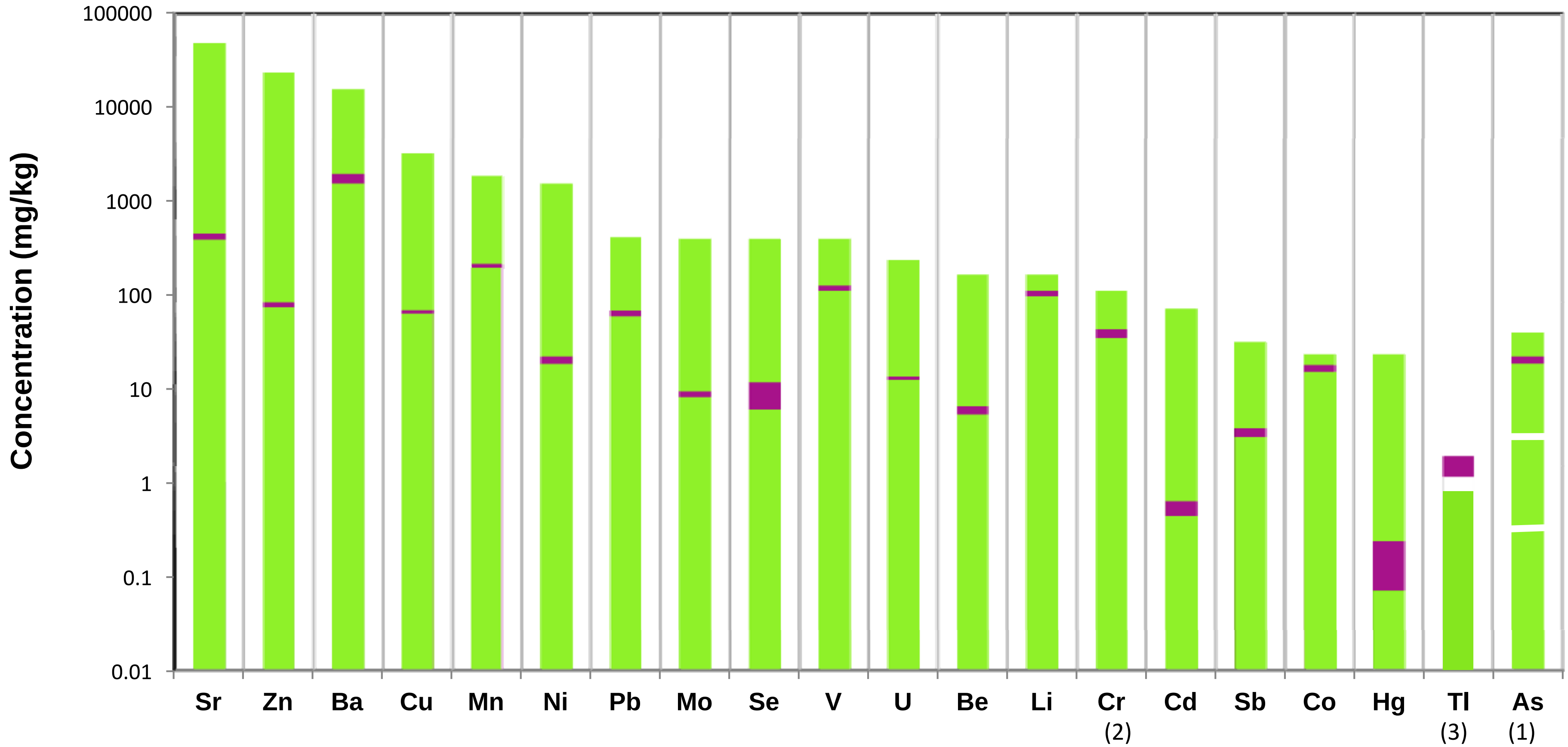
Comparison of USGS Database Constituent Concentrations in Fly Ash Product at the New Mexico Coal Power Plant to the USEPA Regional Screening Levels for Residential Soils



■ Concentration Range (10th - 90th Percentile) in New Mexico Fly Ash Product; USGS 2011

http://pubs.usgs.gov/ds/635/

■ Top of bar corresponds to the USEPA Regional Screening Level (RSL) - Residential Soil (May 2012)

http://www.epa.gov/region9/superfund//prg/index.html

Notes:

(1) Arsenic RSLs for target risk level of 10^{-4} (top of green bar), 10^{-5} (middle white bar), 10^{-6} (lower white bar.

(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.

(3) The RSL for thallium is identified by USEPA as a "provisional value" of "limited usefulness" that was developed for information purposes although USEPA states "it is inappropriate to derive a provisional subchronic or chronic [toxicity value] for thallium" [http://hhpprtv.ornl.gov/issue_papers/ThalliumandCompounds.pdf]

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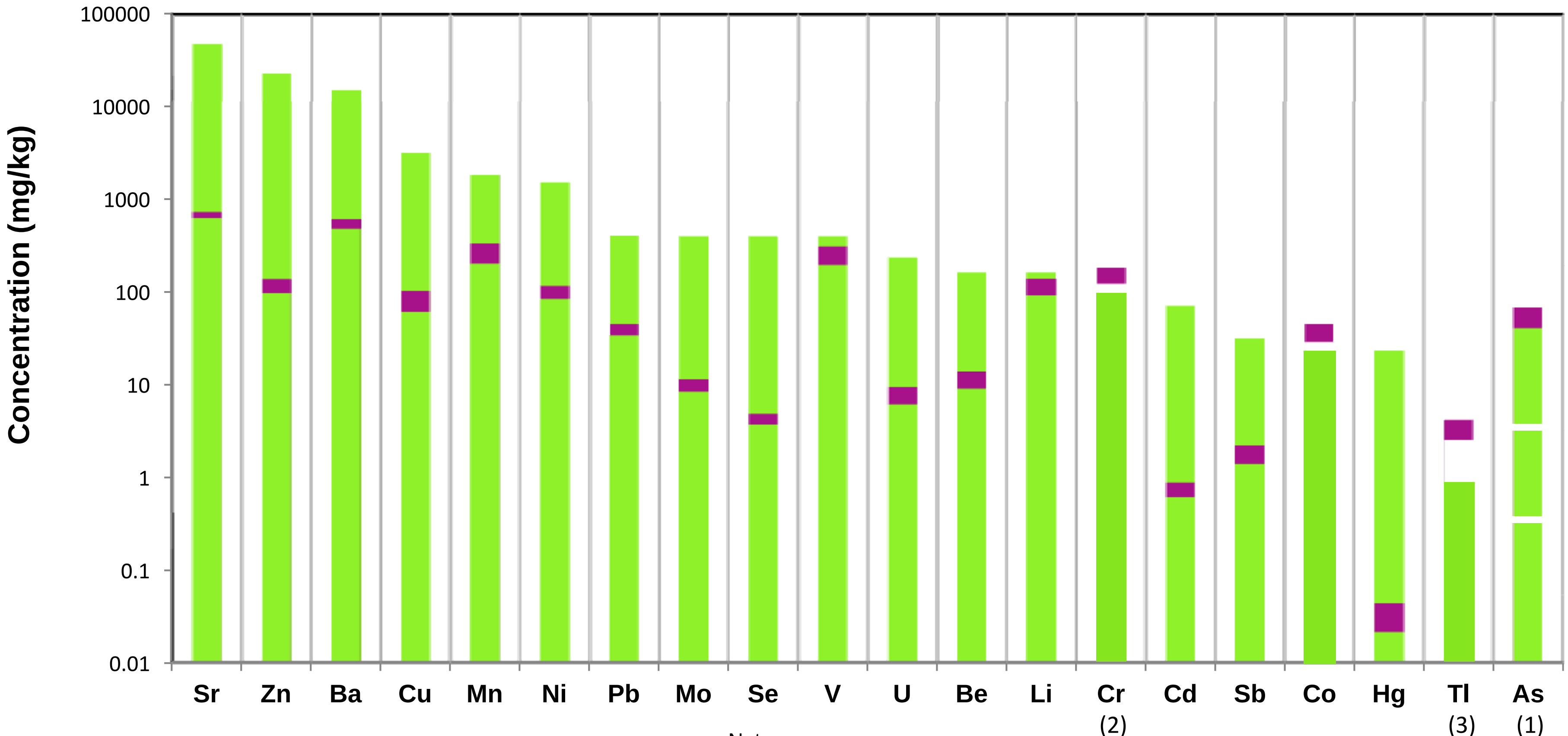
Comparison of USGS Database Constituent Concentrations in Fly Ash at the Ohio Coal Power Plant to the USEPA Regional Screening Levels for Residential Soils



■ Concentration Range (10th - 90th Percentile) in Ohio Fly Ash; USGS 2011
http://pubs.usgs.gov/ds/635/

■ Top of bar corresponds to the USEPA Regional Screening Level (RSL) - Residential Soil (May 2012)
http://www.epa.gov/region9/superfund//prg/index.html

Notes:
(1) Arsenic RSLs for target risk level of 10^{-4} (top of green bar), 10^{-5} (middle white bar), 10^{-6} (lower white bar.
(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.
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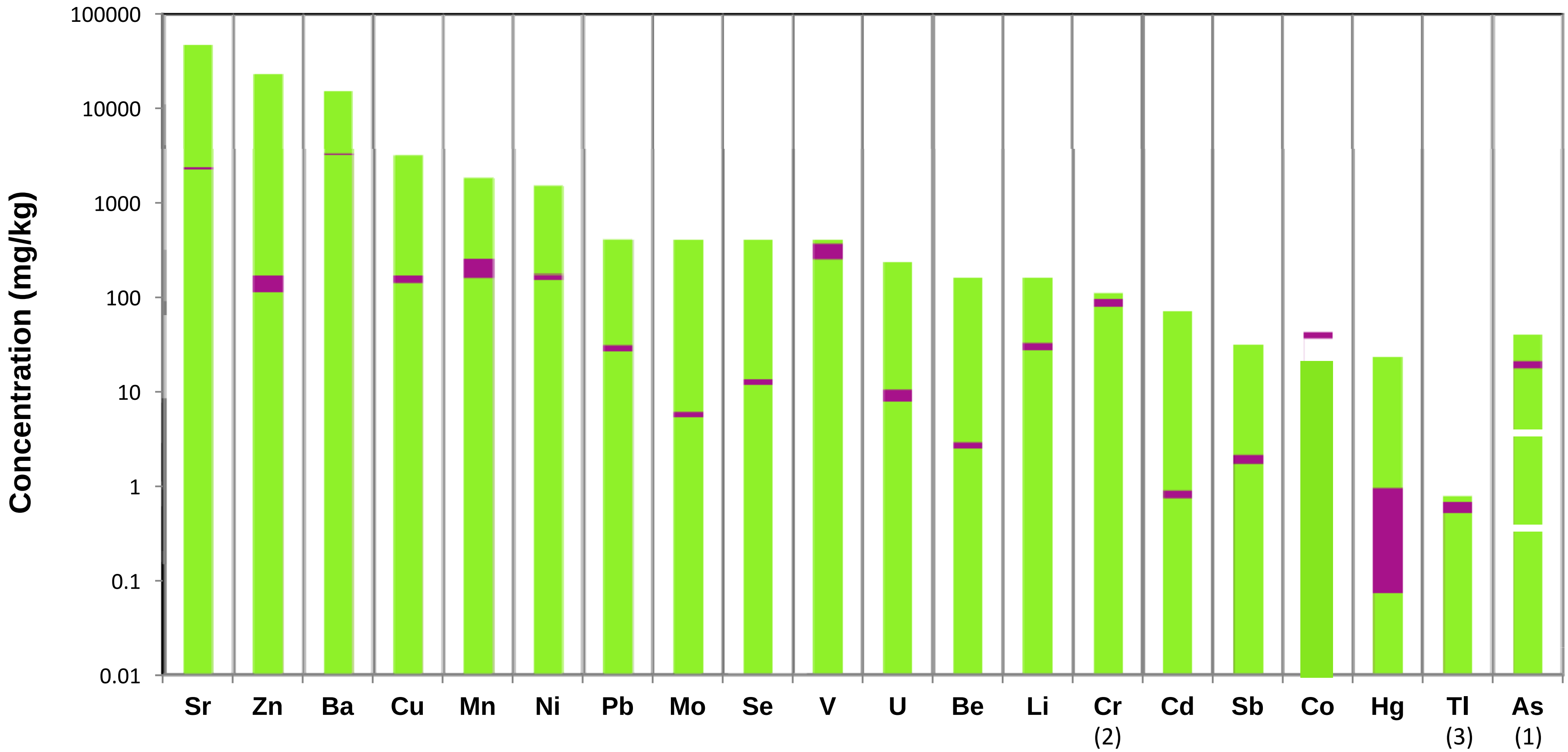
Comparison of USGS Database Constituent Concentrations in Fly Ash at the Wyoming Coal Power Plant to the USEPA Regional Screening Levels for Residential Soils



■ Concentration Range (10th - 90th Percentile) in Wyoming Fly Ash; USGS 2011
http://pubs.usgs.gov/ds/635/

■ Top of bar corresponds to the USEPA Regional Screening Level (RSL) - Residential Soil (May 2012)
http://www.epa.gov/region9/superfund//prg/index.html

Notes:
(1) Arsenic RSLs for target risk level of 10^{-4} (top of green bar), 10^{-5} (middle white bar), 10^{-6} (lower white bar.
(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.
(3) The RSL for thallium is identified by USEPA as a "provisional value" of "limited usefulness" that was developed for information purposes although USEPA states "it is inappropriate to derive a provisional subchronic or chronic [toxicity value] for thallium" [http://hhpprtv.ornl.gov/issue_papers/ThalliumandCompounds.pdf]

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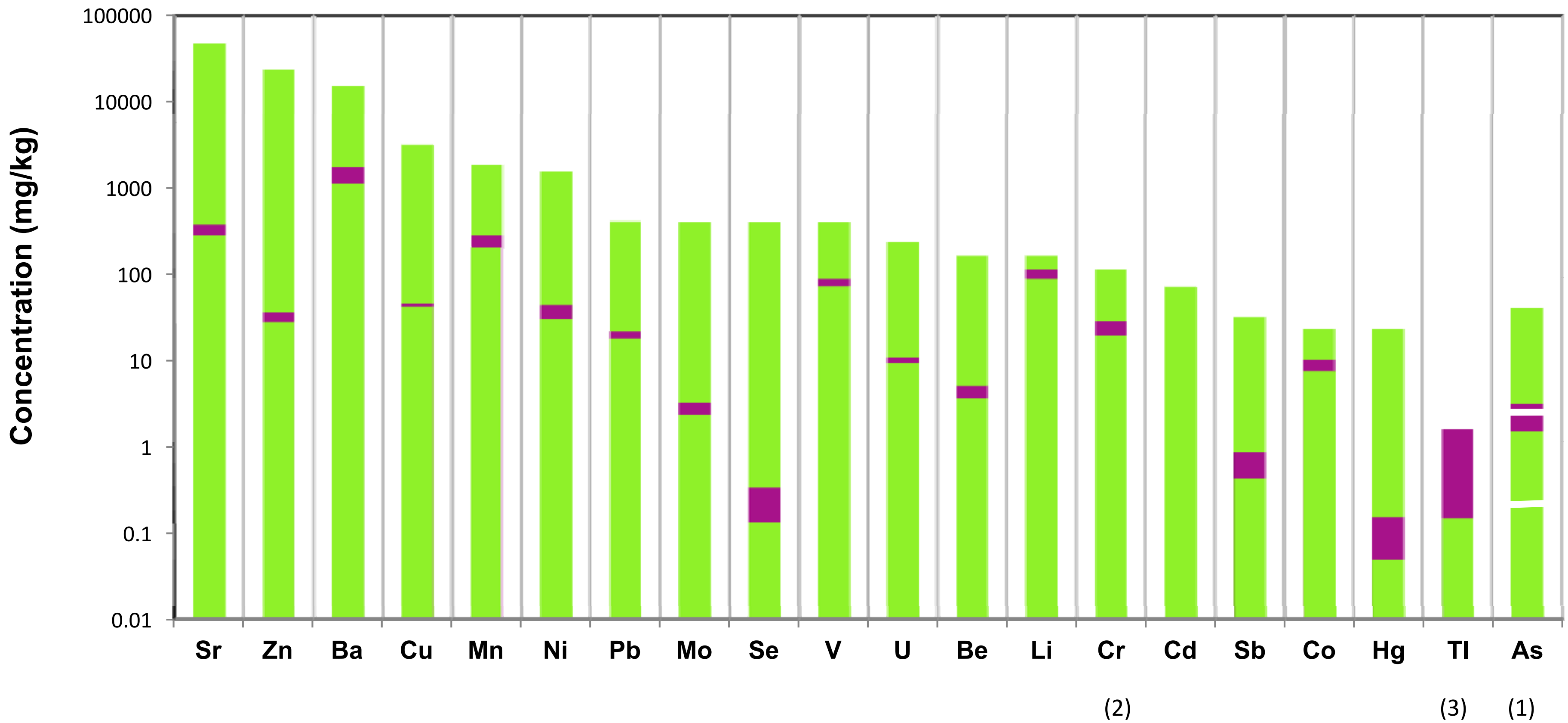
Comparison of the USGS Database Constituent Concentrations in Bottom Ash at the New Mexico Coal Power Plant to the USEPA Regional Screening Levels for Residential Soils



■ Concentration Range (10th - 90th Percentile) in New Mexico Bottom Ash; USGS 2011

http://pubs.usgs.gov/ds/635/

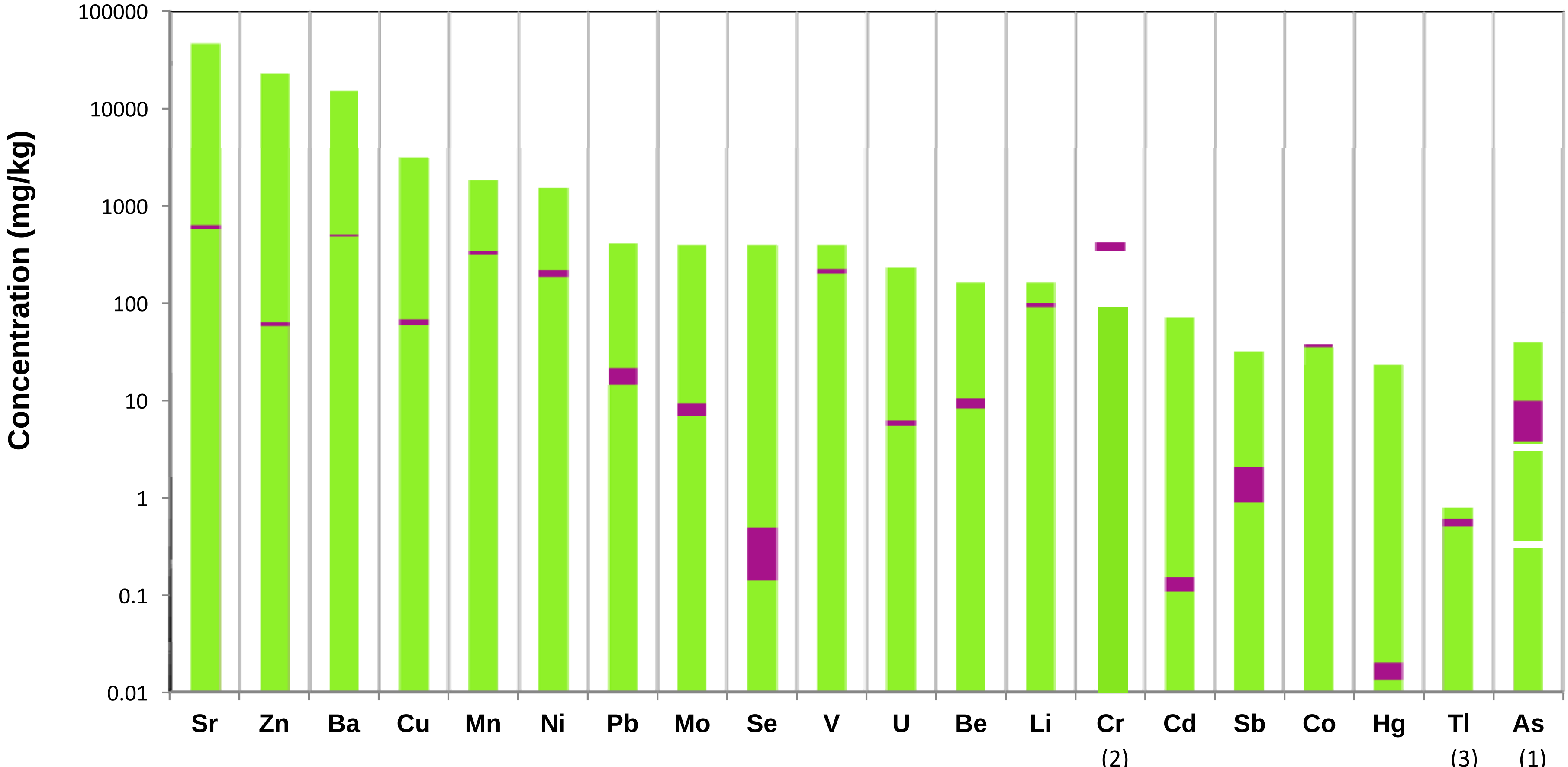
■ Top of bar corresponds to the USEPA Regional Screening Level (RSL) - Residential Soil (May 2012)

http://www.epa.gov/region9/superfund//prg/index.html

Notes:
(1) Arsenic RSLs for target risk level of 10^{-4} (top of green bar), 10^{-5} (middle white bar), 10^{-6} (lower white bar.
(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.
(3) The RSL for thallium is identified by USEPA as a "provisional value" of "limited usefulness" that was developed for information purposes although USEPA states "it is inappropriate to derive a provisional subchronic or chronic [toxicity value] for thallium" [http://hhpprtv.ornl.gov/issue_papers/ThalliumandCompounds.pdf]

AECOM

Comparison of the USGS Database Constituent Concentrations in Bottom Ash at the Ohio Coal Power Plant to the USEPA Regional Screening Levels for Residential Soils



■ Concentration Range (10th - 90th Percentile) in Ohio Bottom Ash; USGS 2011
http://pubs.usgs.gov/ds/635/

■ Top of bar corresponds to the USEPA Regional Screening Level (RSL) - Residential Soil (May 2012)
http://www.epa.gov/region9/superfund//prg/index.html

Notes:
(1) Arsenic RSLs for target risk level of 10^{-4} (top of green bar), 10^{-5} (middle white bar), 10^{-6} (lower white bar.
(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.
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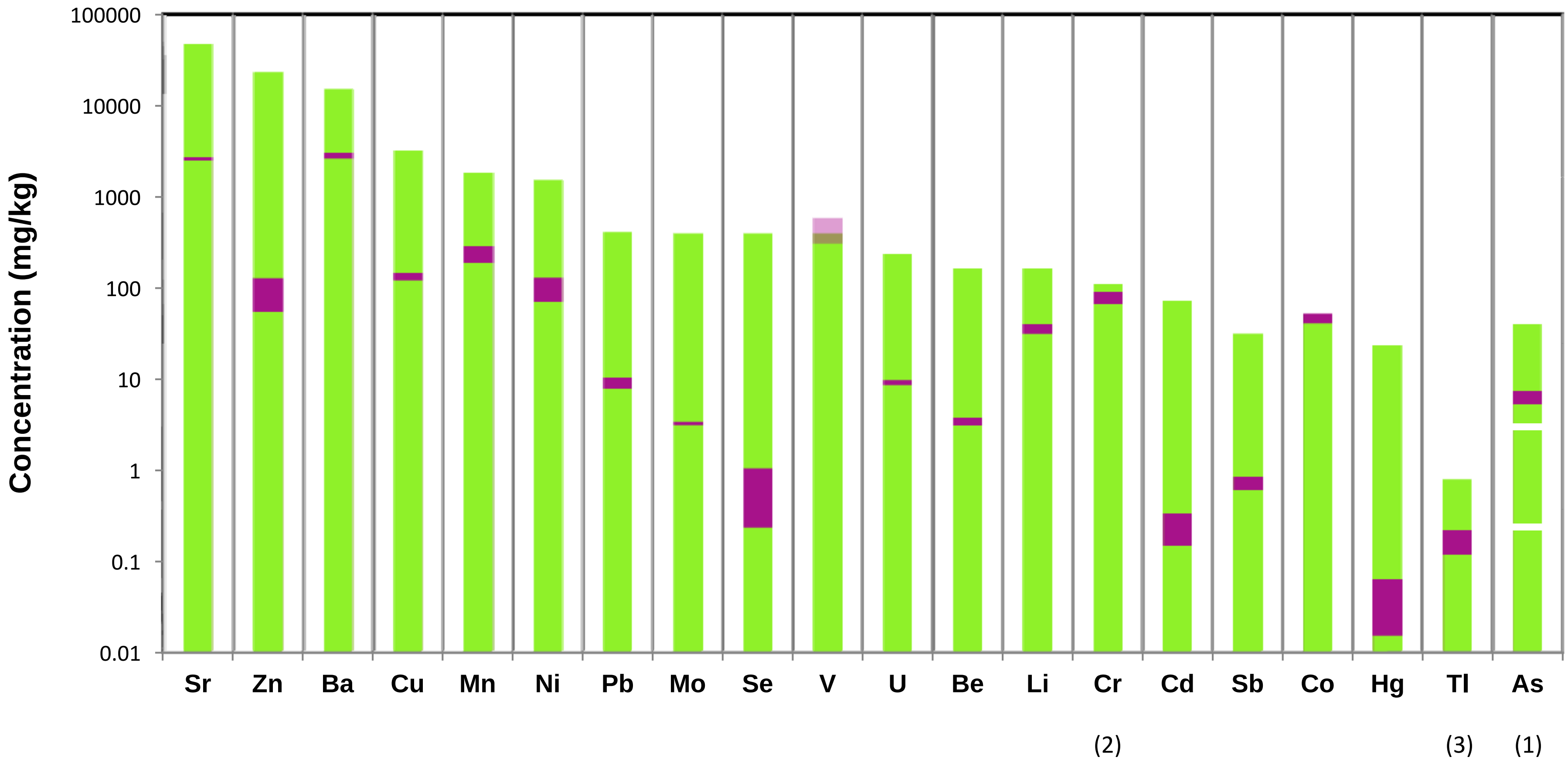
AECOM

Comparison of the USGS Database Constituent Concentrations in Bottom Ash at the Wyoming Coal Power Plant to the USEPA Regional Screening Levels for Residential Soils



■ Concentration Range (10th - 90th Percentile) in Wyoming Bottom Ash; USGS 2011

http://pubs.usgs.gov/ds/635/

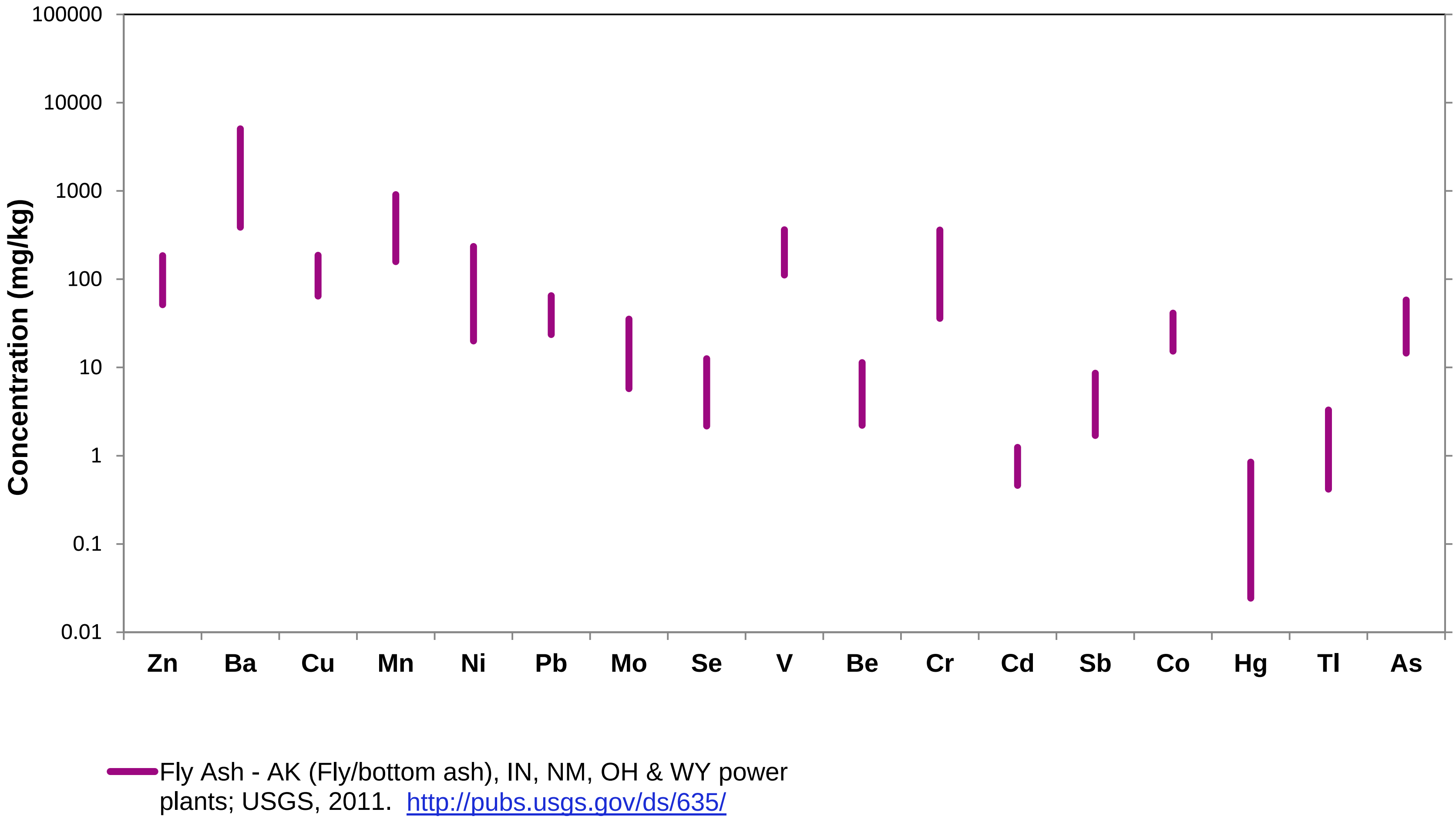
■ Top of bar corresponds to the USEPA Regional Screening Level (RSL) - Residential Soil (May 2012)

http://www.epa.gov/region9/superfund//prg/index.html

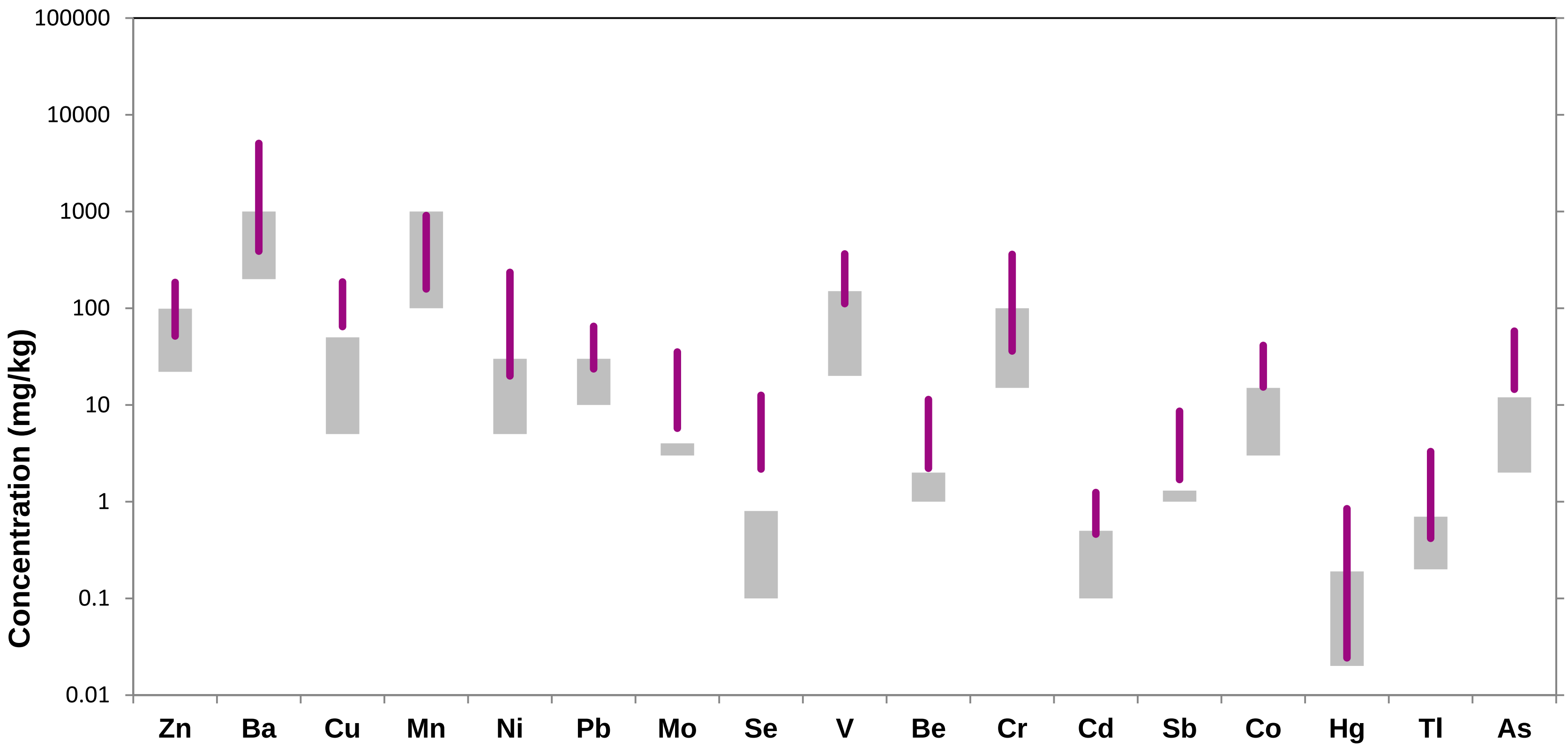
Notes:
(1) Arsenic RSLs for target risk level of 10^{-4} (top of green bar), 10^{-5} (middle white bar), 10^{-6} (lower white bar.
(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.
(3) The RSL for thallium is identified by USEPA as a "provisional value" of "limited usefulness" that was developed for information purposes although USEPA states "it is inappropriate to derive a provisional subchronic or chronic [toxicity value] for thallium" [http://hhpprtv.ornl.gov/issue_papers/ThalliumandCompounds.pdf]

AECOM

10th and 90th percentile USGS Database Constituent Concentrations in Fly Ash



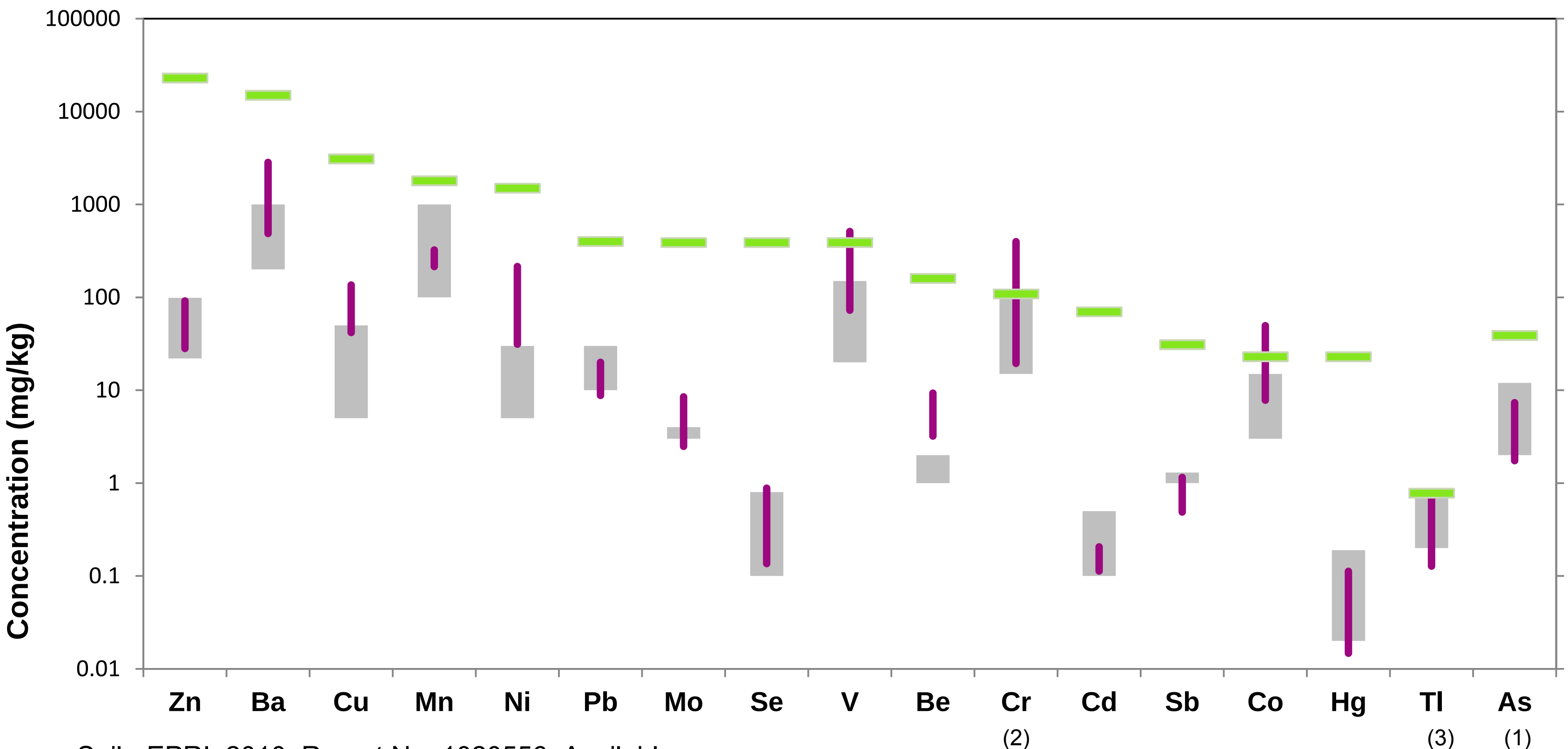
Comparison of 10th and 90th percentile USGS Database Constituent Concentrations in Fly Ash and Background Levels in US Soils



Soil - EPRI, 2010. Report No. 1020556. Available for download at www.epri.com

Fly Ash - AK (Fly/bottom ash), IN, NM, OH & WY power plants; USGS, 2011. http://pubs.usgs.gov/ds/635/

Comparison of 10th and 90th percentile USGS Database Constituent Concentrations in Bottom Ash and Background Levels in US Soils to the USEPA Regional Screening Levels for Residential Soils



Soil - EPRI, 2010. Report No. 1020556. Available for download at www.epri.com

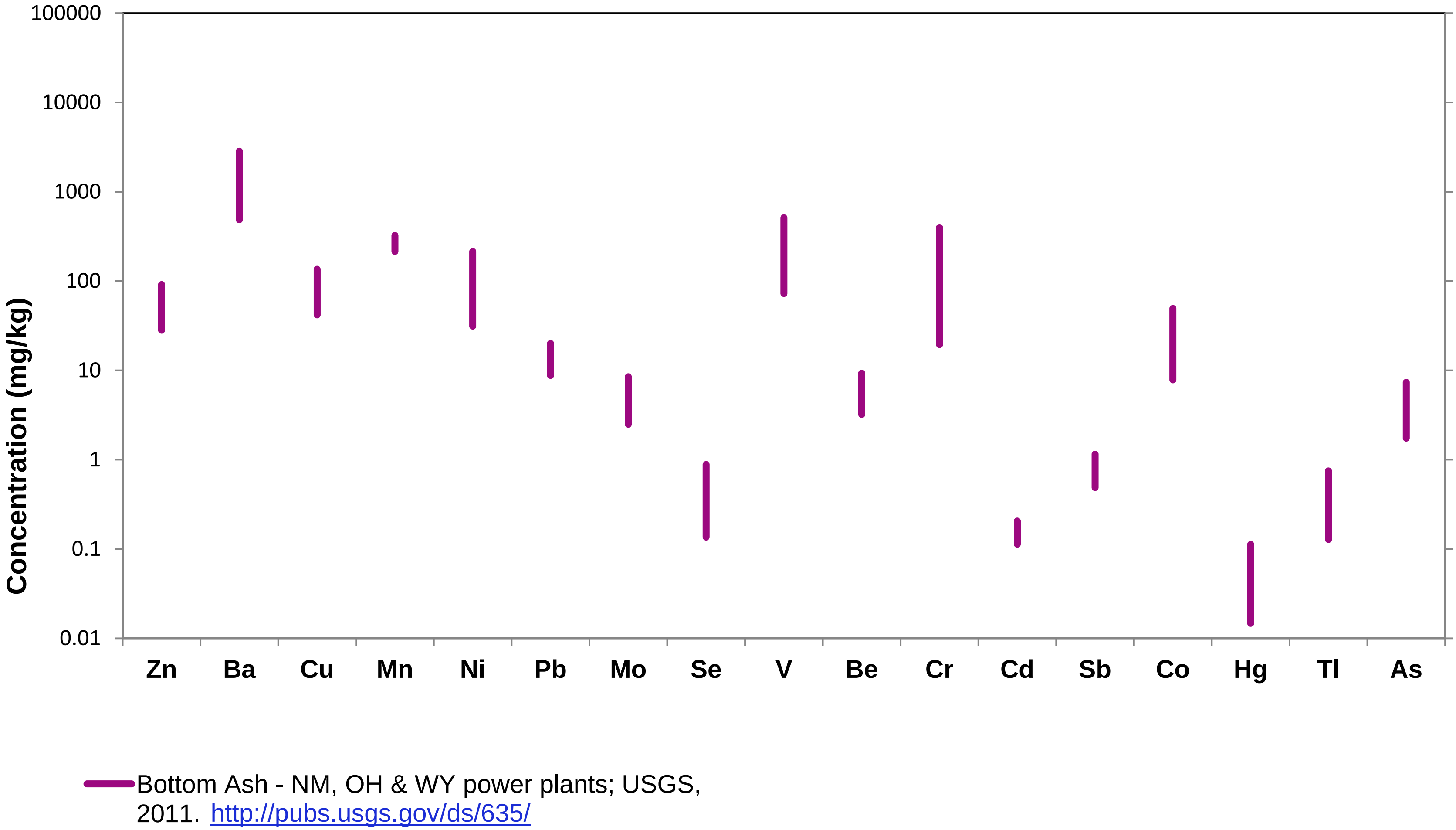
Bottom Ash - NM, OH & WY power plants; USGS, 2011. http://pubs.usgs.gov/ds/635/

USEPA Regional Screening Level (RLS) - Residential Soil (May 2012)

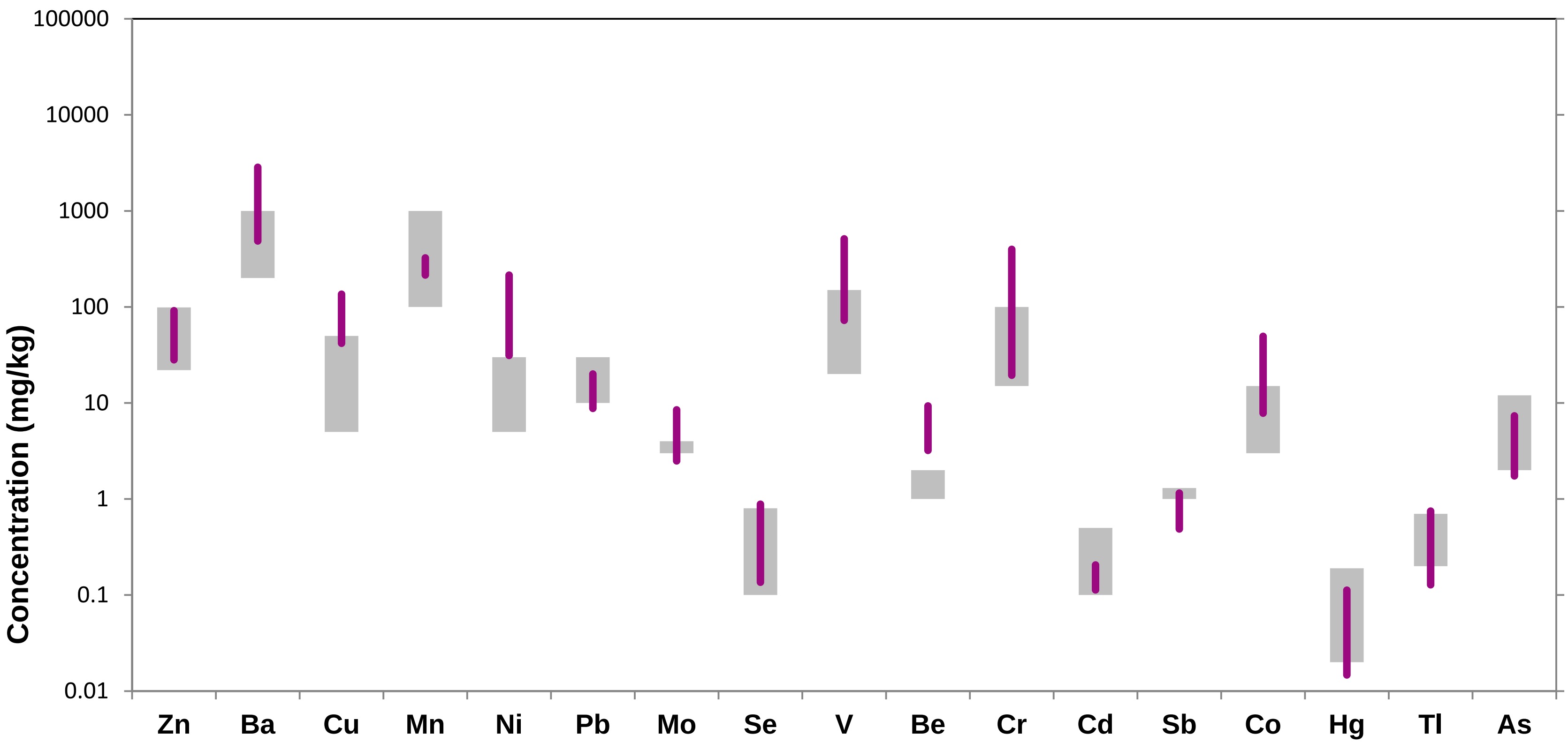
http://www.epa.gov/region9/superfund//prg/index.html

Notes:
(1) Arsenic RSLs for target risk level of 10^{-4}
.
(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.
(3) The RSL for thallium is identified by USEPA as a "provisional value" of "limited usefulness" that was developed for information purposes although USEPA states "it is inappropriate to derive a provisional subchronic or chronic [toxicity value] for thallium" [http://hhpprtv.ornl.gov/issue_papers/ThalliumandCompounds.pdf]

10th and 90th percentile USGS Database Constituent Concentrations in Bottom Ash



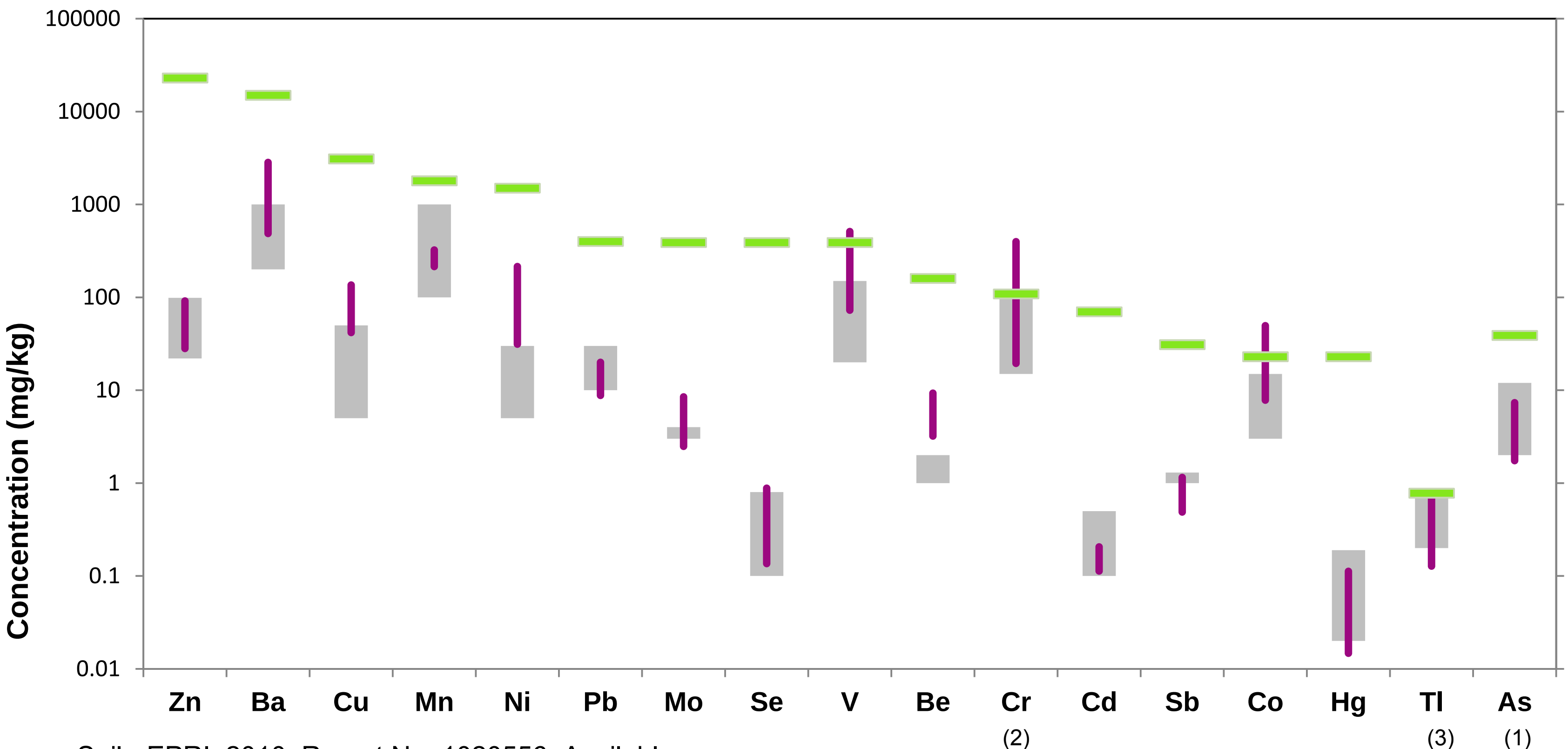
Comparison of 10th and 90th percentile USGS Database Constituent Concentrations in Bottom Ash and Background Levels in US Soils



Soil - EPRI, 2010. Report No. 1020556. Available for download at www.epri.com

Bottom Ash - NM, OH & WY power plants; USGS, 2011. http://pubs.usgs.gov/ds/635/

Comparison of 10th and 90th percentile USGS Database Constituent Concentrations in Bottom Ash and Background Levels in US Soils to the USEPA Regional Screening Levels for Residential Soils



Soil - EPRI, 2010. Report No. 1020556. Available for download at www.epri.com

Bottom Ash - NM, OH & WY power plants; USGS, 2011. http://pubs.usgs.gov/ds/635/

USEPA Regional Screening Level (RLS) - Residential Soil (May 2012)

http://www.epa.gov/region9/superfund//prg/index.html

Notes:

(1) Arsenic RSLs for target risk level of 10^{-4}

.

(2) The screening level shown for chromium is the value calculated using toxicity information for hexavalent chromium currently available on USEPA's IRIS database [http://www.epa.gov/iris/subst/0144.htm]. The screening level for trivalent chromium is 120,000 mg/kg.

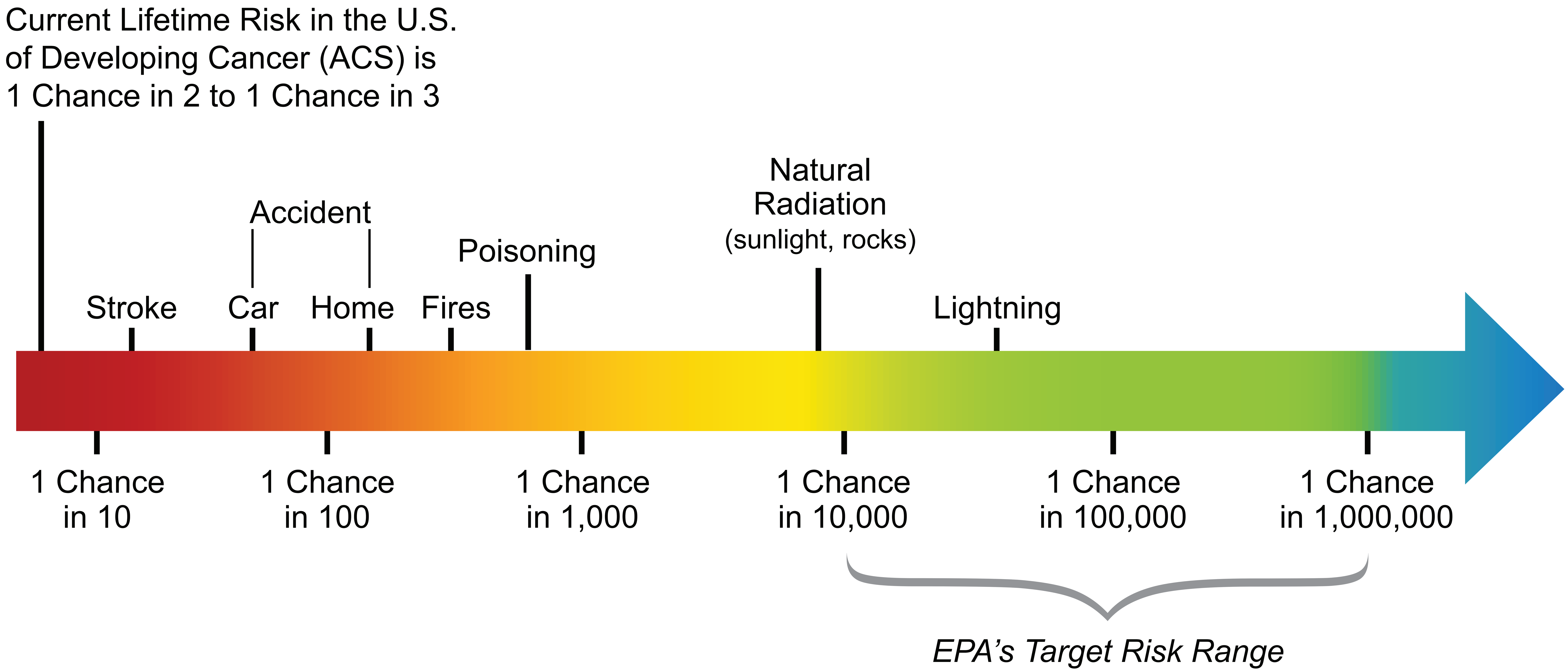
(3) The RSL for thallium is identified by USEPA as a "provisional value" of "limited usefulness" that was developed for information purposes although USEPA states "it is inappropriate to derive a provisional subchronic or chronic [toxicity value] for thallium" [http://hhpprtv.ornl.gov/issue_papers/ThalliumandCompounds.pdf]

Figure 23

Risks in Perspective

AECOM

Range of Lifetime Risk of Fatality Compared with EPA's Target Risk Range



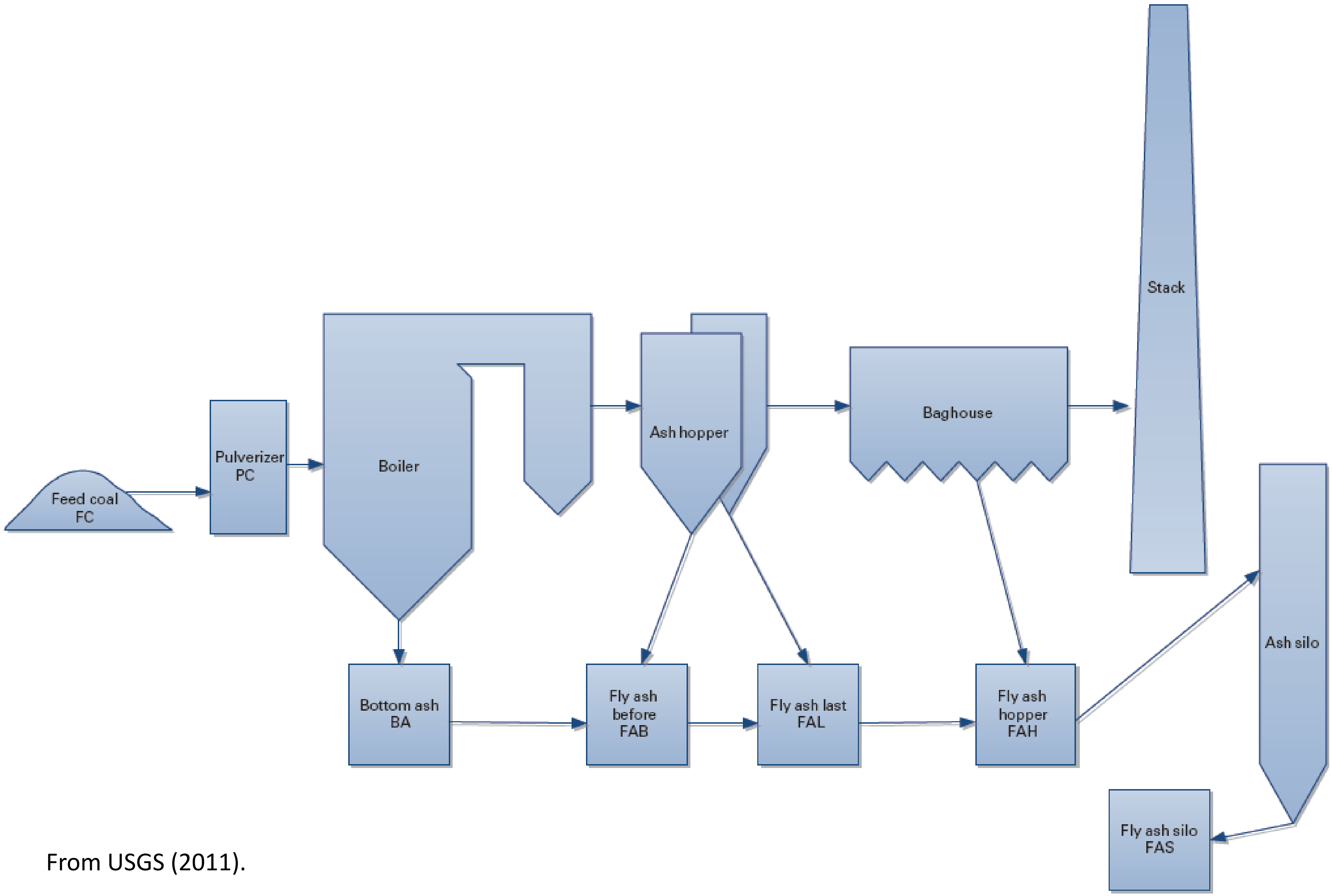
Sources

- *Adapted from U.S. EPA 450/3-90-022, Mar. 1991, http://www.epa.gov/air/oaqps/air_risc/3_90_022.html (1996)*
- *American Cancer Society. Cancer Facts and Figures. Updated Annually. http://www.cancer.org/Research/CancerFactsFigures/index*

Appendix A

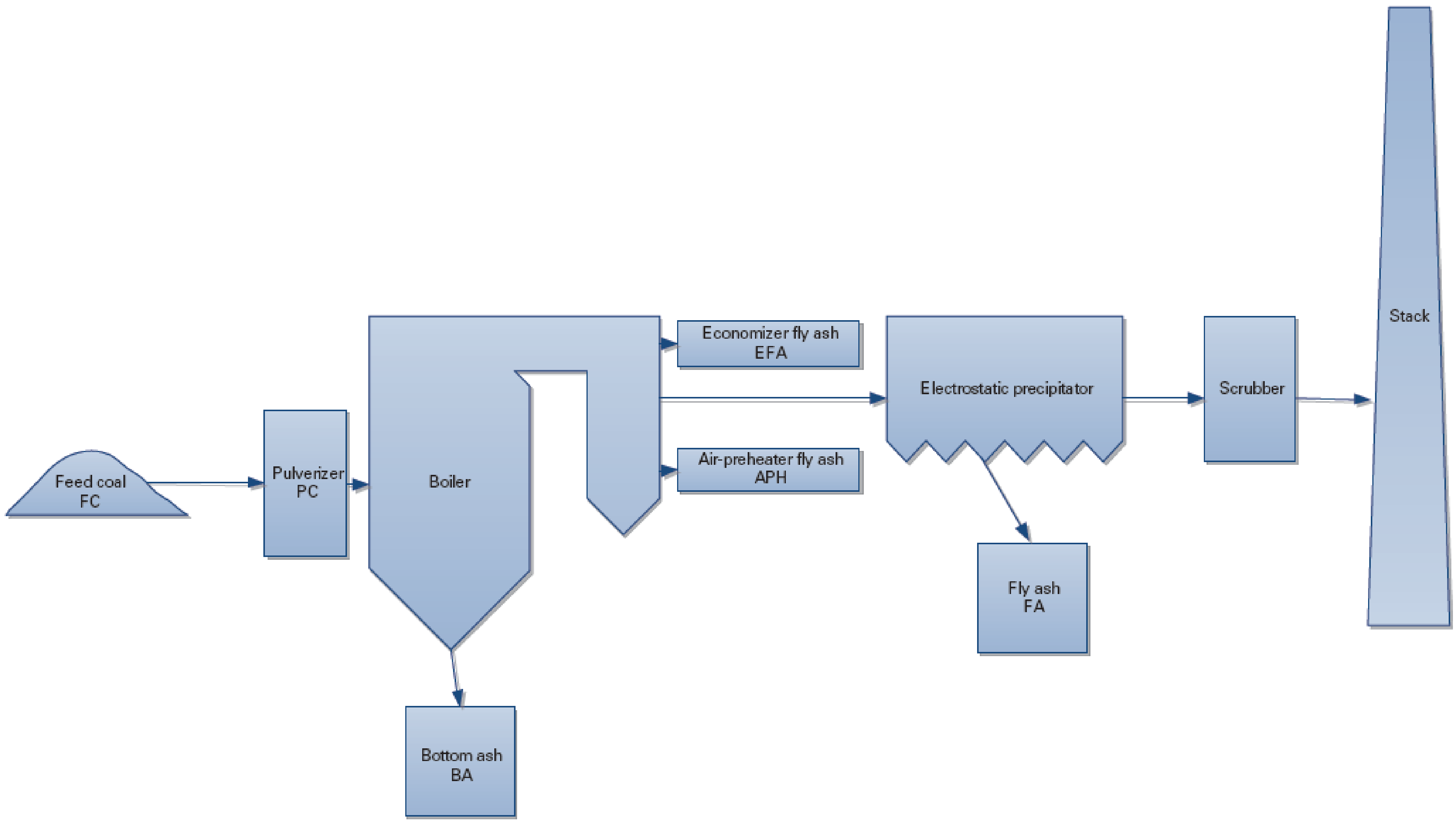
Power Plant Schematics From USGS, 2011

Alaska Power Plant



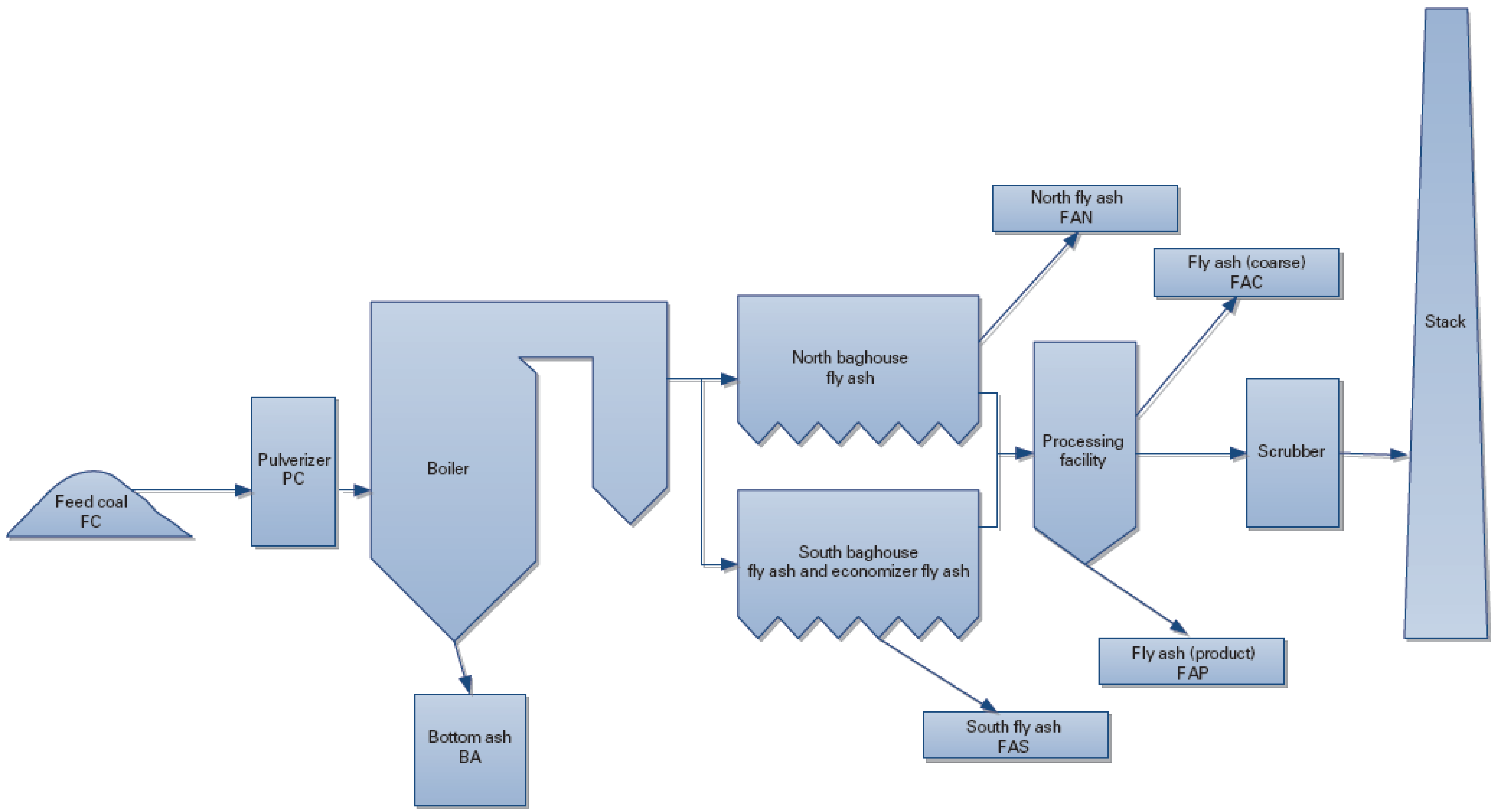
From USGS (2011).

Indiana Power Plant



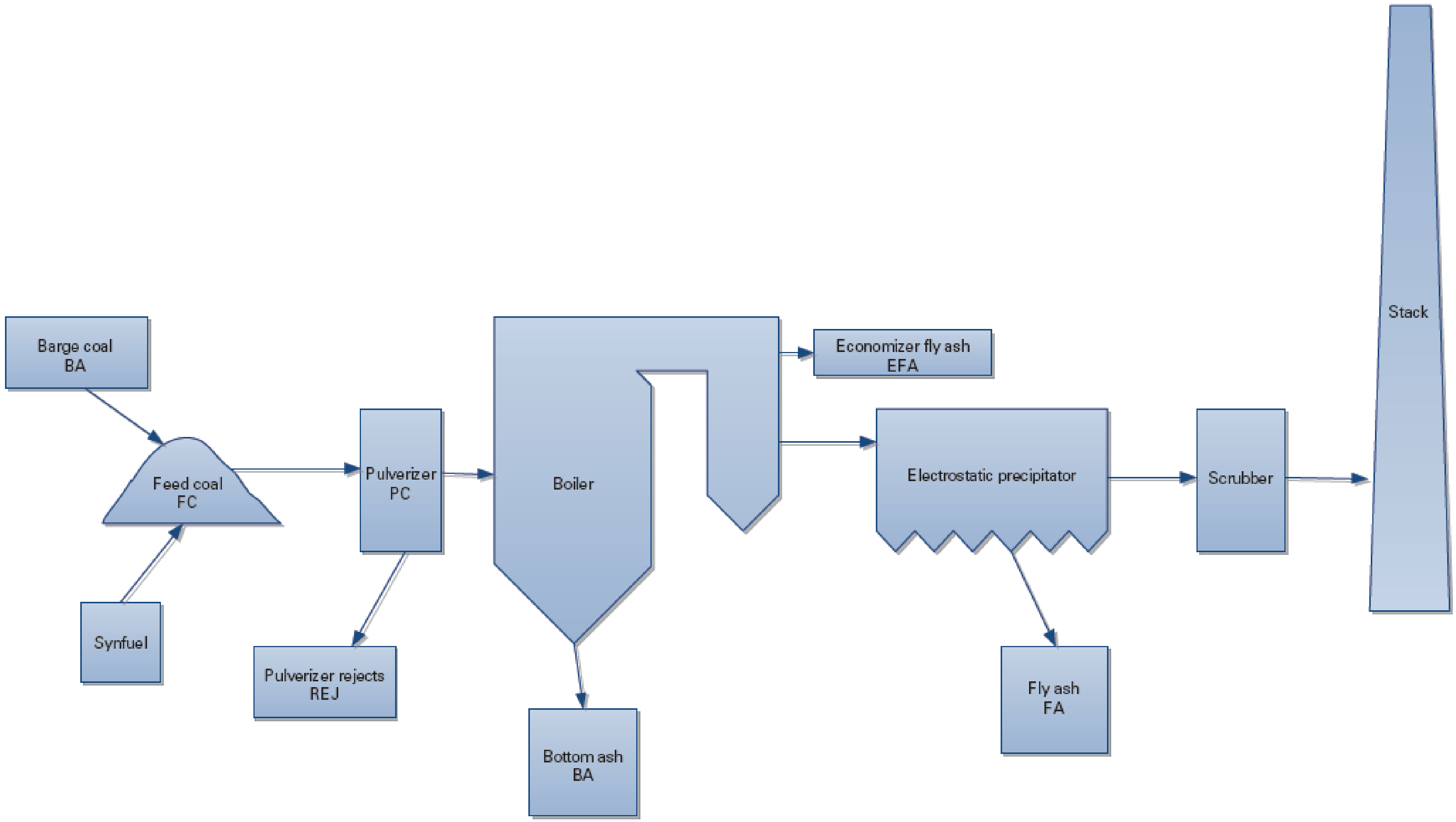
From USGS (2011).

New Mexico Power Plant



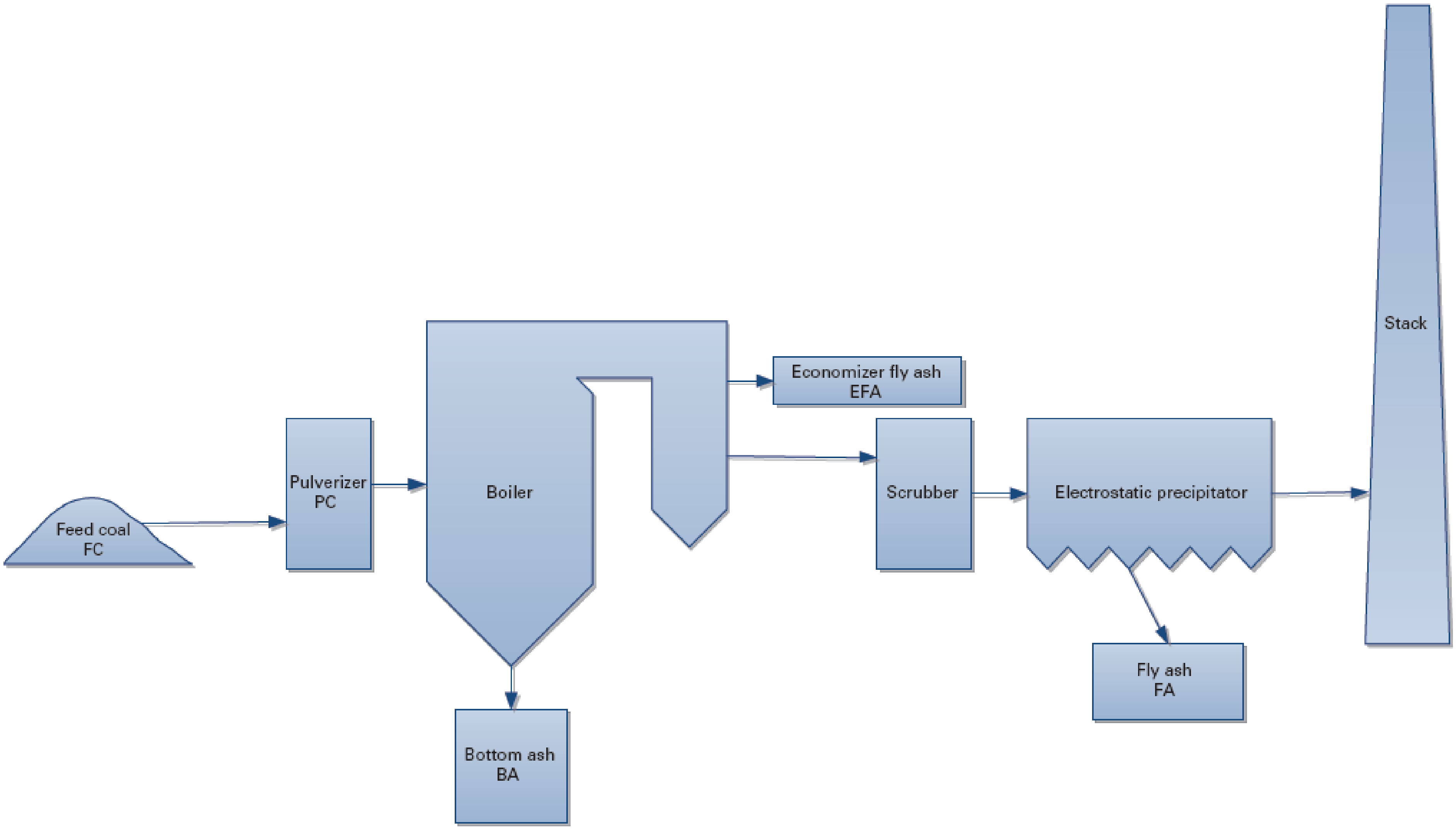
From USGS (2011).

Ohio Power Plant



From USGS (2011).

Wyoming Power Plant



From USGS (2011).

Appendix B

CCP Data Summary Tables From USGS, 2011 - Data Used in the Evaluation

Table 14. Descriptive statistics of ash yield and contents of selected major, minor, and trace elements for fly/bottom ash mix collected from the Alaska power plant.
[All analyses are in percent or parts per million and are reported on an as-determined ash basis except for mercury (Hg) and selenium (Se) which were analyzed on a whole coal basis. Sulfur (S) is reported in percent. Leaders (---) indicate statistics could not be calculated owing to an insufficient number of analyses above the lower detection limit. ND, not determined.]

	Number of samples	Mean	Median	Range Minimum	Range Maximum	Standard deviation
Percent						
SiO_2	19	45.3	45.3	39.9	57.3	3.4
Al_2O_3	19	19.3	19	18.2	23.9	1.23
CaO	19	19.9	19.2	17.2	23.4	1.76
MgO	19	3.37	3.29	2.92	3.78	0.259
Na_2O	19	0.262	0.236	0.148	0.59	0.102
K_2O	19	1.21	1.2	1.09	1.49	0.0776
Fe_2O_3	19	7.72	7.74	6.56	9.22	0.546
TiO_2	19	0.787	0.778	0.745	0.987	0.0501
P_2O_5	19	0.194	0.165	0.128	0.293	0.0585
SO_3	19	1.03	0.883	0.48	1.8	0.374
Parts per million						
As	19	18.8	14.9	7.3	32.9	8.01
Ba	19	4960	4740	4290	5730	450
Be	19	2.34	2.29	1.69	3.16	0.395
Bi	19	0.861	0.629	0.273	1.79	0.479
Cd	19	0.955	0.992	0.38	1.84	0.479
Cl	ND	ND	ND	ND	ND	ND
Co	19	28.8	28.7	24.6	32.6	2.55
Cr	19	408	322	247	925	194
Cs	19	5.61	5.64	4.55	6.15	0.352
Cu	19	153	147	114	197	23.8
Ga	19	26.3	23.9	20.3	34.5	4.32
Ge	19	3.38	2.78	2.13	4.86	1
Hg	19	0.462	0.329	0.123	1.15	0.334
Li	19	23	24.5	13.2	30.4	5.28
Mn	19	873	898	731	966	69.3
Mo	19	34.4	33.4	19.6	45.4	6.61
Nb	19	2.94	2.94	2.44	3.37	0.246
Ni	19	227	226	159	280	31.2
Pb	19	39.1	27.9	14.4	77	20.7
Rb	19	57.6	58.3	49.2	64.8	3.31
S	19	---	---	---	---	---
Sb	19	7.31	7.12	4.21	12.1	2.5
Sc	19	24.5	24.6	20.6	26.5	1.43
Se	19	3.29	2.47	1.25	7.14	1.77
Sr	19	1480	1340	1240	1830	218
Th	19	13.9	13.2	11	17.1	1.86
Tl	19	0.725	0.582	0.312	1.99	0.477
U	19	0.916	0.853	0.682	1.1	0.127
V	19	265	236	203	418	61.4
Y	19	33.3	31.7	27.7	38.4	3.3
Zn	19	76.1	53.5	33.1	233	48

Table 18. Descriptive statistics of ash yield and contents of selected major, minor, and trace elements for all fly ash collected from the Indiana power plant.
[All analyses are in percent or parts per million and are reported on an as-determined ash basis except for mercury (Hg), selenium (Se), and chlorine (Cl), which were analyzed on a whole coal basis. Sulfur (S) is reported in percent. Leaders (---) indicate statistics could not be calculated owing to an insufficient number of analyses above the lower detection limit.]

	Number of samples	Mean	Median	Range		Standard deviation
				Minimum	Maximum	
Percent						
SiO_2	13	41.1	41	39.9	42.8	0.957
Al_2O_3	13	21.5	21.6	19.8	23.5	0.915
CaO	13	1.46	1.45	1.15	1.75	0.188
MgO	13	0.79	0.784	0.712	0.913	0.0481
Na_2O	13	0.384	0.353	0.271	0.54	0.0876
K_2O	13	2.13	2.11	1.88	2.45	0.134
Fe_2O_3	13	25.7	25.5	22.8	28.5	1.64
TiO_2	13	1.09	1.08	1.02	1.16	0.0441
P_2O_5	13	0.181	0.166	0.151	0.245	0.0324
SO_3	13	0.491	0.486	0.262	1.24	0.256
Parts per million						
As	13	26.1	24	20.2	56.3	9.18
Ba	13	379	375	336	422	28.6
Be	13	5.33	2.75	2.32	32.7	8.26
Bi	13	1.05	0.794	0.672	3.96	0.879
Cd	13	1.15	0.981	0.79	3.29	0.663
Cl	13	4.22	1.81	0.1	19.8	5.6
Co	13	45.3	26.7	22.5	264	65.8
Cr	13	169	96.7	78.2	984	246
Cs	13	6.18	2.93	1.62	43.2	11.2
Cu	13	224	175	156	692	142
Ga	13	59.3	38.9	28.7	309	75.4
Ge	13	11.4	3.9	3.24	88.9	23.6
Hg	13	0.038	0.026	0.013	0.104	0.025
Li	13	68.4	24.8	21.6	560	148
Mn	13	201	161	105	723	159
Mo	13	13.7	6.44	5.32	90.5	23.3
Nb	13	29.8	20.5	17.9	142	33.7
Ni	13	108	67.5	58.2	572	140
Pb	13	50.1	30.7	22.1	293	73.2
Rb	13	83.1	28	16.8	709	188
S	13	---	---	---	---	---
Sb	13	4.12	2.38	1.96	22.4	5.54
Sc	13	42.6	27.4	22.5	227	55.5
Se	13	8.62	6.49	4.06	22.5	5
Sr	13	419	379	319	638	108
Th	13	27.2	20.9	17.5	102	22.6
Tl	13	2.13	0.485	0.382	21	5.67
U	13	8.67	6.45	5.33	34.1	7.68
V	13	420	317	262	1660	375
Y	13	86.1	56.6	50.9	410	97.7
Zn	13	120	88	71.5	478	111

Table 20. Descriptive statistics of ash yield and contents of selected major, minor, and trace elements for bottom ash collected from the New Mexico power plant.

[All analyses are in percent or parts per million and are reported on an as-determined ash basis except for mercury (Hg), selenium (Se), and chlorine (Cl), which were analyzed on a whole coal basis. Sulfur (S) is reported in percent. L, less than value shown. Leaders (---) indicate statistics could not be calculated owing to an insufficient number of analyses above the lower detection limit.]

	Number of samples	Mean	Median	Range Minimum	Range Maximum	Standard deviation
			Percent			
SiO_2	18	64.8	64.9	62.8	67.4	1.06
Al_2O_3	18	24.1	24.1	22.8	25.7	0.687
CaO	18	2.95	2.96	2.18	3.57	0.364
MgO	18	0.735	0.678	0.64	0.987	0.114
Na_2O	18	1.04	1.04	0.884	1.19	0.0954
K_2O	18	0.871	0.794	0.656	1.27	0.2
Fe_2O_3	18	4.36	4.24	3.41	5.77	0.701
TiO_2	18	0.821	0.822	0.792	0.838	0.0122
P_2O_5	18	0.123	0.132	0.0779	0.154	0.0248
SO_3	18	0.122	0.117	0.063	0.221	0.0444
			Parts per million			
As	18	3.05	2.18	1.24	18.1	3.8
Ba	18	1420	1440	983	2000	277
Be	18	4.16	4.09	3.41	5.33	0.566
Bi	18	---	---	---	---	---
Cd	18	---	---	---	---	---
Cl	18	24.7	22.2	17.4	42.9	6.78
Co	18	8.58	8.41	7.29	10.6	1.02
Cr	18	22.3	20.7	17.5	30.1	3.83
Cs	18	3.53	2.68	2.42	6.78	1.51
Cu	18	42.9	42.5	40.4	47.5	1.69
Ga	18	18.1	18	16.7	21	0.869
Ge	18	2.22	2.17	1.73	3.28	0.456
Hg	18	0.0208	0.005	0.01L	0.155	0.0423
Li	18	98.4	97.8	82.6	120	10
Mn	18	238	240	159	308	35.6
Mo	18	2.71	2.71	2.15	3.64	0.395
Nb	18	14.3	14.4	13.3	15.9	0.595
Ni	18	35.8	34.9	28.8	49.5	5.83
Pb	18	19.2	19.2	16.5	23	1.67
Rb	18	43.6	36.7	31	71.6	14.4
S	18	---	---	---	---	---
Sb	18	0.623	0.61	0.401	0.911	0.169
Sc	18	12.4	12	11.1	14.3	0.98
Se	18	0.207	0.186	0.1L	0.626	0.132
Sr	18	329	339	270	408	39.1
Th	18	25.3	25.1	23.7	29	1.36
Tl	18	0.446	0.144	0.1L	1.96	0.61
U	18	9.66	9.37	9.03	11	0.573
V	18	77.5	74.1	69.4	95.5	7.79
Y	18	30.1	29.3	27.8	33.9	1.8
Zn	18	32.4	31.1	26.5	53.2	6.18

Table 24. Descriptive statistics of ash yield and contents of selected major, minor, and trace elements for fly ash product collected from the New Mexico power plant.

[All analyses are in percent or parts per million and are reported on an as-determined ash basis except for mercury (Hg), selenium (Se), and chlorine (Cl), which were analyzed on a whole coal basis. Sulfur (S) is reported in percent. L, less than value shown. Leaders (---) indicate statistics could not be calculated owing to an insufficient number of analyses above the lower detection limit.]

	Number of samples	Mean	Median	Range		Standard deviation
				Minimum	Maximum	
Percent						
SiO_2	16	62.8	62.9	60.8	63.7	0.782
Al_2O_3	16	26	26.1	25	26.5	0.45
CaO	16	2.62	2.63	2.37	2.9	0.179
MgO	16	0.821	0.793	0.743	0.98	0.0743
Na_2O	16	1.31	1.29	1.22	1.45	0.0732
K_2O	16	0.89	0.854	0.704	1.14	0.146
Fe_2O_3	16	3.57	3.48	3.23	4.01	0.253
TiO_2	16	0.938	0.934	0.915	0.974	0.0148
P_2O_5	16	0.183	0.186	0.145	0.207	0.0194
SO_3	16	0.07	0.06	0.05 L	0.106	0.01
Parts per million						
As	16	19.6	19.1	16.8	22.2	1.58
Ba	16	1660	1660	1230	1950	178
Be	16	5.75	5.66	5.06	6.69	0.472
Bi	16	2.16	2.16	1.85	2.46	0.174
Cd	16	0.528	0.509	0.42	0.68	0.0799
Cl	16	3.37	2.54	0.1L	8.58	2.47
Co	16	15.8	15.4	14.5	18.3	1.18
Cr	16	37.7	36.1	33.7	45.9	3.68
Cs	16	3.97	3.5	2.9	6.16	1.09
Cu	16	65	65.1	60.8	68.7	2.4
Ga	16	42.4	42.8	39.2	44.5	1.68
Ge	16	10.1	9.62	8.7	11.9	1.06
Hg	16	0.138	0.119	0.0648	0.263	0.0673
Li	16	102	102	91.8	116	6.26
Mn	16	198	194	180	222	10.7
Mo	16	8.63	8.59	7.94	9.35	0.44
Nb	16	17.5	17.6	16.6	18.2	0.465
Ni	16	19.9	20	17.3	22.9	1.5
Pb	16	61.9	62.6	53.8	67.5	4.09
Rb	16	44	40	33.2	64.7	10.2
S	16	---	---	---	---	---
Sb	16	3.27	3.14	2.79	3.78	0.317
Sc	16	12.6	12.4	11.8	13.9	0.679
Se	16	8.39	8.67	1.03	12.2	2.86
Sr	16	402	396	345	476	29.8
Th	16	28	27.8	26.9	30	0.731
Tl	16	1.55	1.33	1.07	2.9	0.458
U	16	12.7	12.7	12	13.5	0.413
V	16	114	112	106	128	6.04
Y	16	34.3	34.1	32.2	36.7	1.37
Zn	16	77.7	78.9	70.4	83.5	4.15

Table 28. Descriptive statistics of ash yield and contents of selected major, minor, and trace elements for bottom ash collected from the Ohio power plant.

[All analyses are in percent or parts per million and are reported on an as-determined ash basis except for mercury (Hg), selenium (Se), and chlorine (Cl), which were analyzed on a whole coal basis. Sulfur (S) is reported in percent. L, less than value shown. Leaders (---) indicate statistics could not be calculated owing to an insufficient number of analyses above the lower detection limit.]

	Number of samples	Mean	Median	Range		Standard deviation
				Minimum	Maximum	
Percent						
SiO_2	15	40	39.5	38.7	45.2	1.66
Al_2O_3	15	17.6	17.6	17.1	18.1	0.259
CaO	15	2.32	2.29	2.14	2.88	0.176
MgO	15	0.594	0.594	0.558	0.645	0.0218
Na_2O	15	0.317	0.32	0.281	0.375	0.023
K_2O	15	1.29	1.28	1.24	1.34	0.0281
Fe_2O_3	15	29.9	30.2	26.8	31.7	1.42
TiO_2	15	0.895	0.899	0.842	0.966	0.0312
P_2O_5	15	0.169	0.17	0.151	0.185	0.00993
SO_3	15	0.197	0.176	0.127	0.378	0.0629
Parts per million						
As	15	5.98	5.27	3.6	12.9	2.75
Ba	15	492	491	474	518	11.3
Be	15	9.02	8.84	7.72	10.3	0.825
Bi	15	0.283	0.249	0.216	0.634	0.105
Cd	15	0.12	0.12	0.1 L	0.169	0.02
Cl	15	20.9	13.8	2.18	61.1	18.5
Co	15	36.2	36.2	34.5	37.7	0.835
Cr	15	377	374	266	461	44.9
Cs	15	5.38	5.39	4.94	5.64	0.187
Cu	15	61.4	60.9	54	69.1	4
Ga	15	20.6	20.7	19.5	22.1	0.784
Ge	15	12.2	12.2	10.9	13.8	0.744
Hg	15	0.0022	---	0.01L	0.0207	0.00822
Li	15	92.8	92.5	86.4	98.6	3.33
Mn	15	321	320	0.5 L	347	14.8
Mo	15	8.12	8.17	6.31	10.2	1.05
Nb	15	21	20.8	19.7	24.6	1.14
Ni	15	202	207	162	240	19.5
Pb	15	17.4	15	13.9	40	6.62
Rb	15	74.1	74.2	69	78.2	2.33
S	15	---	---	---	---	---
Sb	15	1.29	1.02	0.867	3.2	0.645
Sc	15	25.9	26	24	31.5	1.8
Se	15	0.20	---	0.1 L	0.755	0.17
Sr	15	601	615	554	636	29.2
Th	15	16.1	16.1	15.3	17.3	0.511
Tl	15	0.554	0.55	0.446	0.684	0.0547
U	15	5.75	5.63	5.27	7.08	0.435
V	15	209	211	192	221	9.19
Y	15	52.5	52.9	48.1	55.8	2.36
Zn	15	61.2	61.2	55.9	72.9	3.88

Table 30. Descriptive statistics of ash yield and contents of selected major, minor, and trace elements for fly ash collected from the Ohio power plant.
[All analyses are in percent or parts per million and are reported on an as-determined ash basis except for mercury (Hg), selenium (Se), and chlorine (Cl), which were analyzed on a whole coal basis. Sulfur (S) is reported in percent.]

	Number of samples	Mean	Median	Range Minimum	Range Maximum	Standard deviation
			Percent			
SiO_2	13	41.7	42	38.2	43.8	1.68
Al_2O_3	13	18.2	18.5	15.7	19	0.859
CaO	13	2.32	2.41	1.86	2.58	0.23
MgO	13	0.631	0.632	0.566	0.678	0.0293
Na_2O	13	1.75	1.74	1.42	2.15	0.198
K_2O	13	1.47	1.45	1.32	1.65	0.0992
Fe_2O_3	13	26.9	25.8	24	34.8	2.88
TiO_2	13	0.959	0.969	0.87	1	0.0414
P_2O_5	13	0.218	0.217	0.178	0.252	0.0191
SO_3	13	2.46	2.48	1.96	2.91	0.239
			Parts per million			
As	13	59	60.3	33.7	93.8	14.8
Ba	13	530	518	464	608	49.4
Be	13	11.3	11.7	8.03	15.4	2.01
Bi	13	0.997	1.02	0.431	1.48	0.291
Cd	13	0.736	0.789	0.312	0.963	0.172
Cl	13	669	680	394	1270	229
Co	13	36.1	32.6	27.6	46.4	6.62
Cr	13	148	133	118	181	26.2
Cs	13	7.21	6.8	5.6	8.72	1.09
Cu	13	85.2	77.8	55.1	193	35
Ga	13	36.3	34.5	22	47.4	7.51
Ge	13	31.3	31.8	14.4	42.1	7.82
Hg	13	0.0322	0.0318	0.0167	0.0561	0.0109
Li	13	110	97.9	74	140	22.4
Mn	13	253	236	193	333	51.5
Mo	13	10.5	10.6	7.15	18.4	2.69
Nb	13	25.6	22.4	19.2	33	5.02
Ni	13	98	102	79.5	123	14.2
Pb	13	39.1	41.8	21.4	50.4	7.42
Rb	13	92.9	85.8	73.1	115	15
S	13	0.524	0.617	0.3	0.723	0.187
Sb	13	2.05	1.95	0.982	5.3	1.04
Sc	13	28.7	26.8	19.8	37	5.89
Se	13	4.13	4.11	3.49	5.47	0.539
Sr	13	667	648	587	763	49.5
Th	13	18.2	16.2	13.9	23	3.33
Tl	13	3.43	3.37	1.06	6.13	1.13
U	13	7.66	7.3	5.2	9.58	1.51
V	13	248	229	179	317	47.4
Y	13	59.1	55	48	76.7	9.89
Zn	13	111	111	62.7	141	21.9

Table 34. Descriptive statistics of ash yield and contents of selected major, minor, and trace elements for bottom ash collected from the Wyoming power plant.

[All analyses are in percent or parts per million and are reported on an as-determined ash basis except for mercury (Hg), selenium (Se), and chlorine (Cl), which were analyzed on a whole coal basis. Sulfur (S) is reported in percent. L, less than value shown.]

	Number of samples	Mean	Median	Range		Standard deviation
				Minimum	Maximum	
Percent						
SiO_2	15	43.3	43.6	40.4	45.6	1.34
Al_2O_3	15	20	19.7	18.4	21.4	0.847
CaO	15	16.3	16.3	15	17.5	0.701
MgO	15	3.81	3.84	3.27	4.03	0.2
Na_2O	15	0.266	0.219	0.178	0.753	0.139
K_2O	15	0.423	0.422	0.344	0.502	0.0399
Fe_2O_3	15	9.75	9.34	7.21	14.6	1.93
TiO_2	15	1.51	1.52	1.38	1.64	0.0674
P_2O_5	15	0.446	0.445	0.412	0.49	0.021
SO_3	15	0.503	0.449	0.0502	0.998	0.308
Parts per million						
As	15	6.48	6.65	4.99	7.73	0.815
Ba	15	2750	2790	2440	2990	165
Be	15	3.36	3.37	2.99	3.78	0.272
Bi	15	0.222	0.226	0.147	0.268	0.0304
Cd	15	0.20	0.170	0.1 L	0.425	0.090
Cl	15	92.8	102	10.9	173	51.8
Co	15	46	46.1	36.6	55	5
Cr	15	76.2	74.6	62.8	89.9	9.4
Cs	15	5.02	5.01	3.82	5.94	0.558
Cu	15	130	133	110	148	10.8
Ga	15	18	17.9	14.7	20.6	1.55
Ge	15	1.46	1.45	1.23	1.63	0.124
Hg	15	0.0248	0.0187	0.01 L	0.111	0.0307
Li	15	34.9	35.4	29.5	39.3	3.03
Mn	15	250	265	145	282	43.3
Mo	15	3.19	3.21	3	3.37	0.116
Nb	15	44.4	44.8	42	47.9	1.62
Ni	15	93.9	77.3	65.3	255	48.6
Pb	15	9.26	9.52	7.59	10.5	1.02
Rb	15	45.4	44.4	35.4	54	5.04
S	15	0.3	0.3	0.3	0.3	0
Sb	15	0.746	0.773	0.568	1.05	0.122
Sc	15	25.2	25.3	19.4	30.9	3.49
Se	15	0.58	0.40	0.1 L	1.28	0.360
Sr	15	2540	2560	2370	2680	82
Th	15	17.9	18.2	16.6	19.2	0.787
Tl	15	0.166	0.159	0.102	0.294	0.0498
U	15	8.98	8.95	8.44	9.55	0.351
V	15	411	347	279	591	120
Y	15	50.7	51.4	46.7	56.7	3.05
Zn	15	84.9	74	51.7	152	30.7

Table 36. Descriptive statistics of ash yield and contents of selected major, minor, and trace elements for fly ash collected from the Wyoming power plant.
[All analyses are in percent or parts per million and are reported on an as-determined ash basis except for mercury (Hg), selenium (Se), and chlorine (Cl), which were analyzed on a whole coal basis. Sulfur (S) is reported in percent.]

	Number of samples	Mean	Median	Range		Standard deviation
				Minimum	Maximum	
Percent						
SiO_2	15	29	28.9	27.5	31.1	0.971
Al_2O_3	15	15.6	15.7	14.7	16.3	0.46
CaO	15	26.3	26.3	24.9	27.3	0.661
MgO	15	3.34	3.36	3.2	3.47	0.093
Na_2O	15	0.543	0.531	0.463	0.73	0.0642
K_2O	15	0.398	0.398	0.37	0.429	0.0151
Fe_2O_3	15	3.32	3.34	2.87	3.57	0.172
TiO_2	15	1.14	1.14	1.06	1.21	0.0387
P_2O_5	15	0.462	0.459	0.44	0.486	0.0142
SO_3	15	19.2	19.2	17.8	20.3	0.646
Parts per million						
As	15	19.4	20	14.6	22	1.85
Ba	15	3170	3170	2980	3370	84.1
Be	15	2.71	2.74	2.07	3.1	0.239
Bi	15	1.18	1.2	1.04	1.35	0.0917
Cd	15	0.804	0.814	0.699	0.895	0.0613
Cl	15	1080	1050	903	1630	171
Co	15	38.7	39.4	31.4	43.5	3.18
Cr	15	83.6	82.4	54.1	102	10.6
Cs	15	4.57	4.5	4.11	5.7	0.427
Cu	15	149	144	118	171	14.1
Ga	15	29.6	28.8	24.5	34	2.64
Ge	15	2.91	2.91	2.42	3.26	0.237
Hg	15	0.604	0.695	0.021	0.971	0.349
Li	15	29.2	29	21.8	32.9	2.68
Mn	15	215	229	145	283	43.2
Mo	15	5.69	5.78	4.95	6.09	0.293
Nb	15	34.6	34.3	30.7	41.7	3.4
Ni	15	158	158	106	180	17
Pb	15	28.4	28.2	25	33.1	2.03
Rb	15	41.9	39.5	36.4	60.6	7.47
S	15	5.67	5.9	0.727	6.89	1.42
Sb	15	1.92	1.91	1.65	2.11	0.153
Sc	15	25.5	25.5	18.1	29.7	3.07
Se	15	12.4	12.3	11.2	13.5	0.68
Sr	15	2290	2290	2180	2400	58.1
Th	15	14	14.2	11.4	16.8	1.49
Tl	15	0.594	0.593	0.472	0.747	0.0678
U	15	8.75	8.45	7.29	11.2	1.12
V	15	312	317	218	376	46
Y	15	42.6	42.6	34.6	50.3	4.07
Zn	15	135	136	87.9	186	27

Appendix C

CCP Sample-by-Sample Results from USGS, 2011

Table C-1
USGS Sample-by-Sample Results for Fly Ash
For Constituents with USEPA RSLs
American Coal Ash Association

AECOM

PowerPlant	Basin	SAMPLE	Type	As_ppm	Ba_ppm	Be_ppm	Cd_ppm	Co_ppm	Cr_ppm	Cu_ppm	Hg_ppm	Li_ppm	Mn_ppm	Mo_ppm
Indiana	Illinois Basin	07019003	Fly Ash	23	395	2.75	0.887	25.9	93.2	170	0.026	22.5	146	5.83
Indiana	Illinois Basin	07019004	Fly Ash	25.3	367	3.03	1.02	28.2	104	209	0.032	27	182	7.2
Indiana	Illinois Basin	07019005	Fly Ash	24	355	2.64	1.07	28	102	202	0.0337	25.8	163	6.64
Indiana	Illinois Basin	07019006	Fly Ash	24.2	360	2.6	1	26.7	96.7	195	0.0426	24.6	161	6.44
Indiana	Illinois Basin	07019007	Fly Ash	23	336	2.63	0.849	26.6	88.6	173	0.0649	21.6	141	6.14
Indiana	Illinois Basin	07019008	Fly Ash	25.1	352	32.7	3.29	264	984	692	0.0558	560	723	90.5
Indiana	Illinois Basin	07019009	Fly Ash	23.7	410	2.67	0.981	26.6	99.2	189	0.0127	27.5	158	6.5
Indiana	Illinois Basin	07019010	Fly Ash	21.9	422	2.59	0.893	24.4	89.6	172	0.0241	24.8	137	6.07
Indiana	Illinois Basin	07019011	Fly Ash	20.2	383	2.32	0.79	22.5	78.2	156	0.0203	21.7	139	5.32
Indiana	Illinois Basin	07019012	Fly Ash	23.3	352	2.77	0.872	25.1	87.3	175	0.0248	23.2	174	5.86
Indiana	Illinois Basin	07019013	Fly Ash	56.3	418	5.45	1.11	36.2	142	167	0.0219	53.6	199	17.8
Indiana	Illinois Basin	07019014	Fly Ash	25.2	375	3.52	0.805	28	89.5	171	0.0264	23.5	182	6.13
Indiana	Illinois Basin	07019015	Fly Ash	24.5	408	3.59	1.41	26.8	144	239	0.104	33.1	105	8.22
New Mexico	San Juan Basin	E0709002-144	Fly Ash Product	18.4	1610	5.42	0.601	15.1	34.2	67.2	0.085	98	189	8.82
New Mexico	San Juan Basin	E0709002-145	Fly Ash Product	18.7	1600	5.06	0.581	15.2	34.2	66.7	0.0692	98.9	194	8.59
New Mexico	San Juan Basin	E0709002-146	Fly Ash Product	16.8	1640	5.23	0.586	14.8	33.7	62.2	0.0648	104	208	7.94
New Mexico	San Juan Basin	E0709002-147	Fly Ash Product	18.9	1850	5.34	0.51	15.6	36.3	64.8	0.0708	106	211	8.07
New Mexico	San Juan Basin	E0709002-148	Fly Ash Product	18.3	1750	5.58	0.508	15.2	35.9	62.8	0.131	106	205	8.04
New Mexico	San Juan Basin	E0709002-149	Fly Ash Product	18.3	1720	5.17	0.592	14.8	35.6	66.3	0.1	109	200	8.32
New Mexico	San Juan Basin	E0709002-150	Fly Ash Product	20	1560	5.65	0.68	15	35.3	68.3	0.154	102	204	8.87
New Mexico	San Juan Basin	E0709002-151	Fly Ash Product	18.5	1660	5.67	0.496	14.5	35.1	65.5	0.135	108	222	8.58
New Mexico	San Juan Basin	E0709002-152	Fly Ash Product	21	1550	5.63	0.654	15.5	36.4	67.6	0.102	102	203	8.59
New Mexico	San Juan Basin	E0709002-153	Fly Ash Product	21.9	1230	6.12	0.535	17.2	39.4	68.7	0.216	91.8	193	9.35
New Mexico	San Juan Basin	E0709002-154	Fly Ash Product	18.3	1450	5.71	0.462	14.9	35.4	60.8	0.192	103	191	8.25
New Mexico	San Juan Basin	E0709002-155	Fly Ash Product	22.2	1730	5.98	0.49	17.4	41.2	62	0.249	93.5	189	9.34
New Mexico	San Juan Basin	E0709002-156	Fly Ash Product	21.1	1650	6.08	0.461	16.5	41.1	64.5	0.0678	96.4	189	8.9
New Mexico	San Juan Basin	E0709002-157	Fly Ash Product	21.6	1740	6.02	0.427	17.6	43.8	62.7	0.205	96.5	180	8.93
New Mexico	San Juan Basin	E0709002-158	Fly Ash Product	19.3	1950	6.69	0.42	18.3	45.9	65.3	0.263	99.5	190	9.08
New Mexico	San Juan Basin	E0709002-159	Fly Ash Product	20	1930	6.57	0.443	15.9	39.3	64.7	0.106	116	192	8.44
Ohio	Appalachian Basin	07018062	Fly Ash	38.4	464	8.03	0.599	27.6	118	193	0.0311	94.4	228	7.15
Ohio	Appalachian Basin	07018063	Fly Ash	64	532	10.5	0.761	30	124	104	0.0363	95.3	202	11.1
Ohio	Appalachian Basin	07018064	Fly Ash	48.8	546	9.11	0.827	28.2	122	67.7	0.0318	97.9	207	8.28
Ohio	Appalachian Basin	07018065	Fly Ash	33.7	518	10.3	0.312	32.4	133	55.1	0.0245	74	231	8.45
Ohio	Appalachian Basin	07018066	Fly Ash	52.9	570	8.86	0.605	31.6	128	59.4	0.0333	90.3	242	8.94
Ohio	Appalachian Basin	07018067	Fly Ash	56.8	595	11.9	0.63	31.6	124	66.1	0.0435	93.7	193	9.9
Ohio	Appalachian Basin	07018068	Fly Ash	60.3	600	12.2	0.657	32.6	126	72.1	0.0437	95.9	195	10
Ohio	Appalachian Basin	07018069	Fly Ash	67.8	499	11.7	0.862	44.3	181	81.6	0.0167	137	317	10.7
Ohio	Appalachian Basin	07018070	Fly Ash	65.6	474	13.9	0.835	46.4	181	90	0.0245	140	333	10.9
Ohio	Appalachian Basin	07018071	Fly Ash	65.1	503	11.8	0.848	42.2	173	79.4	0.0209	136	330	10.8
Ohio	Appalachian Basin	07018072	Fly Ash	61.2	497	11	0.789	39	162	71.1	0.0225	130	285	10.6
Ohio	Appalachian Basin	07018073	Fly Ash	59.1	487	11.7	0.875	39.7	172	77.8	0.0342	134	288	10.9
Ohio	Appalachian Basin	07018075	Fly Ash	93.8	608	15.4	0.963	43.6	177	90.5	0.0561	112	236	18.4

Notes:
Data from USGS, 2011.
RSL - USEPA Regional Screening Level (USEPA, 2012).
ppm - part per million - milligram per kilogram = mg/kg.

Table C-1
USGS Sample-by-Sample Results for Fly Ash
For Constituents with USEPA RSLs
American Coal Ash Association

AECOM

PowerPlant	Basin	SAMPLE	Type	As_ppm	Ba_ppm	Be_ppm	Cd_ppm	Co_ppm	Cr_ppm	Cu_ppm	Hg_ppm	Li_ppm	Mn_ppm	Mo_ppm
Wyoming	Powder River Basin	07017049	Fly Ash	20.9	3170	2.76	0.699	40.9	76.4	163	0.0371	29	248	5.81
Wyoming	Powder River Basin	07017050	Fly Ash	22	3370	2.87	0.747	43.5	85.5	171	0.0212	27.2	188	5.86
Wyoming	Powder River Basin	07017051	Fly Ash	20	3140	3.1	0.816	39.4	79.9	143	0.132	30.1	159	5.85
Wyoming	Powder River Basin	07017052	Fly Ash	19	3160	2.82	0.75	36.6	79.4	140	0.124	29	242	5.66
Wyoming	Powder River Basin	07017053	Fly Ash	19.2	3180	2.74	0.792	37.3	80.9	141	0.507	29	244	5.55
Wyoming	Powder River Basin	07017054	Fly Ash	20.9	2980	2.74	0.77	37.8	84.1	139	0.773	27.7	213	5.56
Wyoming	Powder River Basin	07017055	Fly Ash	19.2	3170	2.59	0.885	36.5	82.3	140	0.687	28.1	252	5.9
Wyoming	Powder River Basin	07017056	Fly Ash	20	3260	2.76	0.814	41.6	88.2	156	0.695	31	229	5.78
Wyoming	Powder River Basin	07017057	Fly Ash	18.6	3170	2.48	0.753	36.3	81.9	144	0.695	29.6	207	5.26
Wyoming	Powder River Basin	07017058	Fly Ash	19.6	3250	2.74	0.895	39.4	91.5	154	0.842	30.2	283	5.73
Wyoming	Powder River Basin	07017059	Fly Ash	20.7	3180	2.87	0.853	40.8	94.4	160	0.837	32.6	145	6.01
Wyoming	Powder River Basin	07017060	Fly Ash	20.1	3180	2.73	0.893	40.8	91.6	158	0.949	31.6	238	5.81
Wyoming	Powder River Basin	07017061	Fly Ash	14.6	3180	2.07	0.834	31.4	54.1	118	0.943	21.8	164	5.52
Wyoming	Powder River Basin	07017062	Fly Ash	16.3	3110	2.44	0.735	35.8	82.4	138	0.971	27.8	256	4.95
Wyoming	Powder River Basin	07017063	Fly Ash	20	3110	2.88	0.827	42.7	102	168	0.846	32.9	155	6.09
Alaska	Nenana Basin	E0901001-089	Fly Ash/Bottom Ash	32.9	5730	2.5	1.84	30.4	763	197	0.939	30.4	926	33.3
Alaska	Nenana Basin	E0901001-090	Fly Ash/Bottom Ash	29.1	5610	2.87	1.43	30.5	530	184	0.635	27	834	19.6
Alaska	Nenana Basin	E0901001-091	Fly Ash/Bottom Ash	24.8	5490	2.95	1.1	31.3	286	177	0.594	29	867	30.6
Alaska	Nenana Basin	E0901001-092	Fly Ash/Bottom Ash	18.2	5380	3.16	1.12	31.5	925	165	0.364	29.2	852	43.1
Alaska	Nenana Basin	E0901001-093	Fly Ash/Bottom Ash	17.8	5400	2.29	1.09	31.4	375	163	0.344	26.6	859	42.1
Alaska	Nenana Basin	E0901001-094	Fly Ash/Bottom Ash	14.6	4290	1.79	0.529	24.6	262	134	0.329	21.8	915	27.7
Alaska	Nenana Basin	E0901001-095	Fly Ash/Bottom Ash	13.3	4300	2.48	0.537	25.5	343	137	0.317	23.8	933	39
Alaska	Nenana Basin	E0901001-096	Fly Ash/Bottom Ash	13.7	5460	2.06	0.485	25.5	377	140	0.29	25.1	947	43.6
Alaska	Nenana Basin	E0901001-097	Fly Ash/Bottom Ash	7.3	4650	2.79	0.42	27.4	411	126	0.123	27.7	732	45.4
Alaska	Nenana Basin	E0901001-098	Fly Ash/Bottom Ash	10.5	4580	2.43	0.459	28.7	276	132	0.198	18.3	916	28.6
Alaska	Nenana Basin	E0901001-099	Fly Ash/Bottom Ash	14.5	5040	1.84	0.824	25.8	312	140	0.249	24.5	731	34.4
Alaska	Nenana Basin	E0901001-100	Fly Ash/Bottom Ash	14.9	5060	2.39	0.992	27.9	345	147	0.175	26.5	798	39.2
Alaska	Nenana Basin	E0901001-101	Fly Ash/Bottom Ash	11.1	4570	2.24	0.462	28.3	302	128	0.18	17	898	31.5
Alaska	Nenana Basin	E0901001-102	Fly Ash/Bottom Ash	24.1	5210	2.11	1.36	28.8	305	174	0.397	24.7	840	33.4
Alaska	Nenana Basin	E0901001-103	Fly Ash/Bottom Ash	10.7	4610	1.69	0.38	25.3	247	114	0.187	13.2	807	26.3
Alaska	Nenana Basin	E0901001-104	Fly Ash/Bottom Ash	29.2	4740	2.23	1.39	32.6	752	180	0.909	22.2	901	33
Alaska	Nenana Basin	E0901001-105	Fly Ash/Bottom Ash	29.3	4720	2.08	1.74	31.5	305	169	1.15	18.3	966	35.1
Alaska	Nenana Basin	E0901001-106	Fly Ash/Bottom Ash	28.3	4660	2.2	1.43	31.3	322	169	1.14	17.5	948	35.4
Alaska	Nenana Basin	E0901001-107	Fly Ash/Bottom Ash	12.3	4730	2.32	0.55	28.6	305	131	0.261	13.5	917	31.4

Notes:
Data from USGS, 2011.
RSL - USEPA Regional Screening Level (USEPA, 2012).
ppm - part per million - milligram per kilogram = mg/kg.

Table C-1
USGS Sample-by-Sample Results for Fly Ash
For Constituents with USEPA RSLs
American Coal Ash Association

PowerPlant	Basin	SAMPLE	Type	Ni_ppm	Pb_ppm	Sb_ppm	Se_ppm	Sr_ppm	Tl_ppm	U_ppm	V_ppm	Zn_ppm
Indiana	Illinois Basin	07019003	Fly Ash	69.2	27	2.28	6.49	386	0.473	6.05	297	179
Indiana	Illinois Basin	07019004	Fly Ash	75.1	30.9	2.47	8.11	618	0.499	6.8	330	307
Indiana	Illinois Basin	07019005	Fly Ash	67.2	31.2	2.43	11.4	638	0.489	6.86	323	179
Indiana	Illinois Basin	07019006	Fly Ash	64.8	31.9	2.38	8.52	498	0.485	6.84	317	191
Indiana	Illinois Basin	07019007	Fly Ash	64.3	27.3	2.23	22.5	459	0.462	6.09	295	163
Indiana	Illinois Basin	07019008	Fly Ash	572	293	22.4	14	441	21	34.1	1660	848
Indiana	Illinois Basin	07019009	Fly Ash	68.1	30.7	2.45	5.91	362	0.609	6.45	324	183
Indiana	Illinois Basin	07019010	Fly Ash	61.5	26.8	2.29	6.18	319	0.478	6.14	296	161
Indiana	Illinois Basin	07019011	Fly Ash	58.2	24.6	2.05	5.83	322	0.437	5.33	262	145
Indiana	Illinois Basin	07019012	Fly Ash	64.8	26.1	2.24	5.66	379	0.443	6.11	291	187
Indiana	Illinois Basin	07019013	Fly Ash	95	36.3	4.43	4.06	331	1.3	7.24	364	237
Indiana	Illinois Basin	07019014	Fly Ash	75.2	22.1	1.96	8.68	363	0.382	6.19	262	122
Indiana	Illinois Basin	07019015	Fly Ash	67.5	44	3.89	4.75	327	0.673	8.46	434	195
New Mexico	San Juan Basin	E0709002-144	Fly Ash Product	20.1	66.4	3.13	6.65	389	1.07	12.6	109	75.9
New Mexico	San Juan Basin	E0709002-145	Fly Ash Product	18.1	63.6	2.97	9.79	371	1.14	12.2	111	75.2
New Mexico	San Juan Basin	E0709002-146	Fly Ash Product	20	60.4	2.79	8.99	408	1.14	12	106	73.2
New Mexico	San Juan Basin	E0709002-147	Fly Ash Product	19.6	62.6	3.01	7.87	446	1.27	12.3	108	78.3
New Mexico	San Juan Basin	E0709002-148	Fly Ash Product	17.3	62.5	3.09	10.5	420	1.33	12.4	110	74.1
New Mexico	San Juan Basin	E0709002-149	Fly Ash Product	18.3	65.8	2.99	10.7	406	1.3	12.6	111	83.5
New Mexico	San Juan Basin	E0709002-150	Fly Ash Product	20	67.5	3.15	11.2	384	1.33	12.7	112	80.6
New Mexico	San Juan Basin	E0709002-151	Fly Ash Product	18.5	63.7	3.04	8.35	417	1.3	12.7	109	70.5
New Mexico	San Juan Basin	E0709002-152	Fly Ash Product	18.8	67.4	3.16	12.2	387	1.31	12.9	114	76
New Mexico	San Juan Basin	E0709002-153	Fly Ash Product	20.6	60	3.42	6.76	345	1.78	12.7	121	81.9
New Mexico	San Juan Basin	E0709002-154	Fly Ash Product	19.2	58.5	3.12	11.4	409	1.53	12.4	110	70.4
New Mexico	San Juan Basin	E0709002-155	Fly Ash Product	20.8	57.1	3.66	6.59	397	1.86	12.8	119	82.2
New Mexico	San Juan Basin	E0709002-156	Fly Ash Product	22.9	59.3	3.57	10.2	395	1.77	12.9	119	80
New Mexico	San Juan Basin	E0709002-157	Fly Ash Product	21.9	56.8	3.75	6.82	388	1.88	13	121	80
New Mexico	San Juan Basin	E0709002-158	Fly Ash Product	21.6	53.8	3.78	1.03	395	2.9	13.5	128	81.5
New Mexico	San Juan Basin	E0709002-159	Fly Ash Product	20.4	64.7	3.63	5.19	476	1.85	13.5	114	79.4
Ohio	Appalachian Basin	07018062	Fly Ash	86.4	41.8	1.36	3.89	636	2.39	6.53	188	98.9
Ohio	Appalachian Basin	07018063	Fly Ash	83	41.8	1.95	4.86	648	3.55	7.3	216	111
Ohio	Appalachian Basin	07018064	Fly Ash	79.5	34.4	1.51	4.26	699	3.22	6.83	209	96.8
Ohio	Appalachian Basin	07018065	Fly Ash	105	21.4	0.982	3.65	587	1.06	5.2	179	62.7
Ohio	Appalachian Basin	07018066	Fly Ash	86.6	33.2	1.64	4.2	763	3.08	5.88	219	95.2
Ohio	Appalachian Basin	07018067	Fly Ash	83.5	33.2	1.67	4.23	702	3.01	6.5	220	96
Ohio	Appalachian Basin	07018068	Fly Ash	87.4	34.8	1.72	4.11	705	3.19	6.62	229	101
Ohio	Appalachian Basin	07018069	Fly Ash	115	43.6	2.17	4.19	640	4.15	9.04	299	136
Ohio	Appalachian Basin	07018070	Fly Ash	123	43.7	1.97	3.72	612	3.74	9.58	306	126
Ohio	Appalachian Basin	07018071	Fly Ash	109	44.4	2.19	3.49	638	3.98	9.37	288	131
Ohio	Appalachian Basin	07018072	Fly Ash	102	41.9	2.03	3.85	645	3.77	8.96	270	122
Ohio	Appalachian Basin	07018073	Fly Ash	105	43.3	2.17	3.71	663	3.37	9.23	284	126
Ohio	Appalachian Basin	07018075	Fly Ash	108	50.4	5.3	5.47	728	6.13	8.58	317	141

Notes:
Data from USGS, 2011.
RSL - USEPA Regional Screening Level (USEPA, 2012).
ppm - part per million - milligram per kilogram = mg/kg.

Table C-1
USGS Sample-by-Sample Results for Fly Ash
For Constituents with USEPA RSLs
American Coal Ash Association

AECOM

PowerPlant	Basin	SAMPLE	Type	Ni_ppm	Pb_ppm	Sb_ppm	Se_ppm	Sr_ppm	Tl_ppm	U_ppm	V_ppm	Zn_ppm
Wyoming	Powder River Basin	07017049	Fly Ash	154	28.2	1.65	13.1	2290	0.596	11	240	186
Wyoming	Powder River Basin	07017050	Fly Ash	171	29.1	1.67	12.2	2380	0.629	11.2	258	169
Wyoming	Powder River Basin	07017051	Fly Ash	158	29	2.11	11.3	2230	0.694	9.53	293	120
Wyoming	Powder River Basin	07017052	Fly Ash	149	27.8	1.96	12.8	2290	0.609	8.51	297	112
Wyoming	Powder River Basin	07017053	Fly Ash	158	27.6	1.9	13.5	2270	0.569	8.27	309	136
Wyoming	Powder River Basin	07017054	Fly Ash	168	26.4	1.91	13.2	2310	0.552	8.39	317	153
Wyoming	Powder River Basin	07017055	Fly Ash	148	26.1	1.89	11.8	2400	0.472	7.98	315	113
Wyoming	Powder River Basin	07017056	Fly Ash	166	29.8	2.02	11.2	2300	0.585	8.93	341	116
Wyoming	Powder River Basin	07017057	Fly Ash	151	27.1	1.86	12	2340	0.537	8.04	322	112
Wyoming	Powder River Basin	07017058	Fly Ash	165	28.9	2.07	12.9	2310	0.593	8.45	348	147
Wyoming	Powder River Basin	07017059	Fly Ash	167	33.1	2.1	11.8	2330	0.619	8.68	367	165
Wyoming	Powder River Basin	07017060	Fly Ash	170	29.4	2	12.1	2290	0.593	8.34	363	118
Wyoming	Powder River Basin	07017061	Fly Ash	106	27.2	1.9	12.4	2230	0.606	7.44	218	87.9
Wyoming	Powder River Basin	07017062	Fly Ash	153	25	1.67	12.3	2180	0.504	7.29	321	155
Wyoming	Powder River Basin	07017063	Fly Ash	180	30.9	2.04	12.7	2240	0.747	9.17	376	138
Alaska	Nenana Basin	E0901001-089	Fly Ash/Bottom Ash	228	77	12.1	5.96	1830	0.882	1.03	375	143
Alaska	Nenana Basin	E0901001-090	Fly Ash/Bottom Ash	159	63.6	11.2	4.66	1800	0.854	1.04	345	97
Alaska	Nenana Basin	E0901001-091	Fly Ash/Bottom Ash	212	52.3	9.84	3.94	1750	0.756	1.01	255	76.5
Alaska	Nenana Basin	E0901001-092	Fly Ash/Bottom Ash	273	41.1	8.76	3	1690	1.84	1.1	418	63.3
Alaska	Nenana Basin	E0901001-093	Fly Ash/Bottom Ash	265	38.6	7.8	2.93	1670	0.784	1.09	257	60.8
Alaska	Nenana Basin	E0901001-094	Fly Ash/Bottom Ash	183	25	5.13	2.05	1340	0.582	0.842	232	51.5
Alaska	Nenana Basin	E0901001-095	Fly Ash/Bottom Ash	241	24.4	5.27	2.43	1320	0.413	0.853	235	51.6
Alaska	Nenana Basin	E0901001-096	Fly Ash/Bottom Ash	258	23.4	5.08	2.3	1640	0.423	0.843	236	49.4
Alaska	Nenana Basin	E0901001-097	Fly Ash/Bottom Ash	280	14.4	4.55	1.25	1330	0.313	1.08	234	33.1
Alaska	Nenana Basin	E0901001-098	Fly Ash/Bottom Ash	200	21.5	5.18	1.81	1240	0.312	0.791	236	48.8
Alaska	Nenana Basin	E0901001-099	Fly Ash/Bottom Ash	226	27.9	6.48	2.47	1590	0.397	0.906	223	51.1
Alaska	Nenana Basin	E0901001-100	Fly Ash/Bottom Ash	248	23.9	7.12	1.87	1590	0.396	1.01	247	53.5
Alaska	Nenana Basin	E0901001-101	Fly Ash/Bottom Ash	222	18.1	4.51	1.83	1240	0.4	0.83	231	42.1
Alaska	Nenana Basin	E0901001-102	Fly Ash/Bottom Ash	215	53.3	8.78	3.95	1680	0.737	1.04	244	78.7
Alaska	Nenana Basin	E0901001-103	Fly Ash/Bottom Ash	187	18.3	4.21	1.64	1250	0.314	0.682	203	39.1
Alaska	Nenana Basin	E0901001-104	Fly Ash/Bottom Ash	223	70.3	10.6	6	1320	0.925	0.849	369	111
Alaska	Nenana Basin	E0901001-105	Fly Ash/Bottom Ash	227	65	8.56	7.14	1260	1.99	0.814	238	114
Alaska	Nenana Basin	E0901001-106	Fly Ash/Bottom Ash	242	62.9	8.63	5.52	1260	0.987	0.751	232	233
Alaska	Nenana Basin	E0901001-107	Fly Ash/Bottom Ash	221	21.6	5	1.77	1300	0.471	0.847	234	48.7

Notes:
Data from USGS, 2011.
RSL - USEPA Regional Screening Level (USEPA, 2012).
ppm - part per million - milligram per kilogram = mg/kg.

Table C-2
USGS Sample-by-Sample Results for Bottom Ash
For Constituents with USEPA RSLs
American Coal Ash Association

PowerPlant	Basin	SAMPLE	Type	As_ppm	Ba_ppm	Be_ppm	Cd_ppm	Co_ppm	Cr_ppm	Cu_ppm	Hg_ppm	Li_ppm	Mn_ppm	Mo_ppm
New Mexico	San Juan Basin	E0709002-076	Bottom Ash	3.37	1350	3.81	0.1	8.54	19.4	43	0.01	99	244	2.72
New Mexico	San Juan Basin	E0709002-077	Bottom Ash	1.45	1180	3.55	0.1	7.83	18	41.5	0.01	93.4	234	2.43
New Mexico	San Juan Basin	E0709002-078	Bottom Ash	1.66	1080	3.41	0.1	7.79	17.5	43.9	0.01	89.2	242	2.52
New Mexico	San Juan Basin	E0709002-079	Bottom Ash	1.47	1510	3.92	0.1	8.93	30.1	44.5	0.01	101	267	2.69
New Mexico	San Juan Basin	E0709002-080	Bottom Ash	2.16	1510	3.88	0.1	8.28	20.7	41.9	0.01	109	250	2.85
New Mexico	San Juan Basin	E0709002-081	Bottom Ash	1.57	1440	3.97	0.1	7.34	19.3	42.2	0.01	106	225	2.15
New Mexico	San Juan Basin	E0709002-082	Bottom Ash	1.94	1140	3.54	0.1	7.93	19.6	45.4	0.01	94.4	261	2.83
New Mexico	San Juan Basin	E0709002-083	Bottom Ash	2.68	1380	3.42	0.1	7.68	19.4	41.5	0.01	106	262	2.72
New Mexico	San Juan Basin	E0709002-084	Bottom Ash	2.56	1660	4.66	0.1	8.25	21.9	41.9	0.01	107	308	3.51
New Mexico	San Juan Basin	E0709002-085	Bottom Ash	18.1	1120	4.16	0.1	8.81	20.7	43.6	0.155	89	292	3.64
New Mexico	San Juan Basin	E0709002-086	Bottom Ash	2.95	983	4.09	0.1	9.91	22.7	47.5	0.0307	87.6	230	3.04
New Mexico	San Juan Basin	E0709002-087	Bottom Ash	2.28	1470	4.16	0.1	7.31	20.7	41.6	0.01	120	218	2.32
New Mexico	San Juan Basin	E0709002-088	Bottom Ash	1.8	1430	4.08	0.1	7.29	19.5	40.4	0.01	109	210	2.18
New Mexico	San Juan Basin	E0709002-089	Bottom Ash	2.19	1590	4.15	0.1	8.94	23.6	41.6	0.01	89.2	228	2.68
New Mexico	San Juan Basin	E0709002-090	Bottom Ash	2.9	1140	5.33	0.1	9.61	26	42.8	0.01	96.5	240	2.73
New Mexico	San Juan Basin	E0709002-091	Bottom Ash	2.73	1610	4.79	0.1	9.34	26.6	43.6	0.113	104	239	2.79
New Mexico	San Juan Basin	E0709002-092	Bottom Ash	1.78	1880	4.97	0.1	10.1	27.6	42	0.01	87.8	159	2.35
New Mexico	San Juan Basin	E0709002-093	Bottom Ash	1.24	2000	4.94	0.1	10.6	28.3	42.8	0.01	82.6	176	2.62
Wyoming	Powder River Basin	07017064	Bottom Ash	7.73	2790	3.53	0.176	51.3	89.9	139	0.0151	39.3	148	3.35
Wyoming	Powder River Basin	07017065	Bottom Ash	6.98	2780	3.45	0.181	49.4	87	137	0.0506	37.5	145	3.21
Wyoming	Powder River Basin	07017066	Bottom Ash	7.09	2640	3.48	0.198	50.4	83.8	135	0.01	36.4	240	3.22
Wyoming	Powder River Basin	07017067	Bottom Ash	6.75	2880	3.37	0.174	49.8	81.5	133	0.111	35.4	282	3.18
Wyoming	Powder River Basin	07017068	Bottom Ash	7.18	2450	3.74	0.147	46.1	88.8	147	0.0227	39	257	3.16
Wyoming	Powder River Basin	07017069	Bottom Ash	5.33	2440	3.78	0.1	46.1	84.5	133	0.01	38.2	269	3.04
Wyoming	Powder River Basin	07017070	Bottom Ash	6.95	2640	3.65	0.166	46.3	79.9	138	0.0187	35.7	274	3.26
Wyoming	Powder River Basin	07017071	Bottom Ash	4.99	2870	3.23	0.138	43.3	74.6	125	0.0404	36	282	3
Wyoming	Powder River Basin	07017072	Bottom Ash	6.22	2840	3.15	0.161	36.6	70.8	123	0.01	33.8	247	3.26
Wyoming	Powder River Basin	07017073	Bottom Ash	6.65	2980	3.37	0.158	41	70.6	125	0.01	33.5	271	3.37
Wyoming	Powder River Basin	07017074	Bottom Ash	7.29	2790	2.99	0.425	55	65.5	118	0.0576	30	271	3.28
Wyoming	Powder River Basin	07017075	Bottom Ash	6.03	2990	2.99	0.217	49.6	62.8	110	0.0192	29.5	263	3.08
Wyoming	Powder River Basin	07017076	Bottom Ash	5.16	2680	3.12	0.379	39.3	65.3	148	0.01	33.7	264	3
Wyoming	Powder River Basin	07017077	Bottom Ash	6.21	2840	3.01	0.148	42.9	65.2	118	0.0229	32.1	266	3.15
Wyoming	Powder River Basin	07017078	Bottom Ash	6.63	2690	3.61	0.15	43.3	73.2	128	0.0145	32.7	265	3.24
Ohio	Appalachian Basin	07018016	Bottom Ash	4.56	477	8.84	0.114	37	377	66	0.01	98.6	320	8.64
Ohio	Appalachian Basin	07018017	Bottom Ash	4.18	474	7.72	0.127	35.1	370	69.1	0.01	89.1	0.5	9.21
Ohio	Appalachian Basin	07018018	Bottom Ash	3.71	483	9.73	0.104	35.7	374	60.9	0.01	96.8	313	7.95
Ohio	Appalachian Basin	07018019	Bottom Ash	3.92	500	10.3	0.127	36.2	360	62.7	0.01	97.7	296	7.71
Ohio	Appalachian Basin	07018020	Bottom Ash	7.47	490	9.4	0.127	37.7	396	62.6	0.01	93.4	339	8.38
Ohio	Appalachian Basin	07018021	Bottom Ash	6.69	500	9.28	0.13	35.8	372	58.8	0.01	90	320	8.17
Ohio	Appalachian Basin	07018022	Bottom Ash	11.1	496	10.1	0.154	36.3	266	62.7	0.01	90.3	330	6.31
Ohio	Appalachian Basin	07018023	Bottom Ash	12.9	518	10.3	0.169	36.9	412	67.9	0.01	90.6	336	10.2
Ohio	Appalachian Basin	07018024	Bottom Ash	3.6	483	8.77	0.104	37.1	423	61.3	0.01	93.8	347	8.8
Ohio	Appalachian Basin	07018025	Bottom Ash	4.47	484	9.12	0.119	36.2	351	59.5	0.0123	93.9	335	7.3
Ohio	Appalachian Basin	07018026	Bottom Ash	5.27	488	8.2	0.1	35.9	408	59	0.0207	92.2	320	8.39
Ohio	Appalachian Basin	07018027	Bottom Ash	3.79	491	8.38	0.1	37.1	461	60.1	0.01	94.8	320	9.28
Ohio	Appalachian Basin	07018028	Bottom Ash	5.5	501	8.71	0.115	35.8	401	57.9	0.01	91.9	320	7.91
Ohio	Appalachian Basin	07018029	Bottom Ash	6.91	501	8.45	0.125	36.2	349	58	0.01	92.5	313	6.81
Ohio	Appalachian Basin	07018030	Bottom Ash	5.65	493	7.99	0.112	34.5	335	54	0.01	86.4	307	6.75

Notes:
Data from USGS, 2011.
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ppm - part per million - milligram per kilogram = mg/kg.

Table C-2
USGS Sample-by-Sample Results for Bottom Ash
For Constituents with USEPA RSLs
American Coal Ash Association

PowerPlant	Basin	SAMPLE	Type	Ni_ppm	Pb_ppm	Sb_ppm	Se_ppm	Sr_ppm	Tl_ppm	U_ppm	V_ppm	Zn_ppm
New Mexico	San Juan Basin	E0709002-076	Bottom Ash	28.8	19.8	0.586	0.275	321	0.115	9.35	73.8	30.4
New Mexico	San Juan Basin	E0709002-077	Bottom Ash	30.8	19.2	0.413	0.18	292	0.1	9.3	73.8	33.7
New Mexico	San Juan Basin	E0709002-078	Bottom Ash	32.1	18.6	0.401	0.194	275	0.1	9.11	71.6	27.2
New Mexico	San Juan Basin	E0709002-079	Bottom Ash	34.4	19.5	0.634	0.127	359	0.1	9.23	73.1	31.8
New Mexico	San Juan Basin	E0709002-080	Bottom Ash	36.4	16.5	0.469	0.379	348	1.57	9.37	70.7	26.5
New Mexico	San Juan Basin	E0709002-081	Bottom Ash	32.7	18.1	0.411	0.21	340	0.144	9.18	70.1	29.6
New Mexico	San Juan Basin	E0709002-082	Bottom Ash	30.2	20.5	0.507	0.191	291	0.1	9.35	75.6	53.2
New Mexico	San Juan Basin	E0709002-083	Bottom Ash	31.5	19.3	0.478	0.15	338	0.1	9.36	74.4	35.7
New Mexico	San Juan Basin	E0709002-084	Bottom Ash	35.4	18	0.545	0.228	372	0.1	9.58	73.2	27.7
New Mexico	San Juan Basin	E0709002-085	Bottom Ash	37.7	23	0.773	0.626	279	1.09	9.03	76.8	28.4
New Mexico	San Juan Basin	E0709002-086	Bottom Ash	41.1	18.4	0.698	0.264	270	0.747	9.3	86.1	35.8
New Mexico	San Juan Basin	E0709002-087	Bottom Ash	30	22.8	0.718	0.121	408	0.291	10.3	71.1	27.6
New Mexico	San Juan Basin	E0709002-088	Bottom Ash	28.9	19.8	0.492	0.148	361	0.1	9.9	69.4	27.4
New Mexico	San Juan Basin	E0709002-089	Bottom Ash	37.6	17.1	0.654	0.158	345	0.153	9.58	78.5	29.8
New Mexico	San Juan Basin	E0709002-090	Bottom Ash	43.3	19.2	0.911	0.253	351	0.376	10.2	86.3	33.9
New Mexico	San Juan Basin	E0709002-091	Bottom Ash	49.5	19.5	0.811	0.13	364	1.96	10.1	84.5	32.5
New Mexico	San Juan Basin	E0709002-092	Bottom Ash	40.4	19	0.834	0.1	315	0.59	10.7	91.1	36.2
New Mexico	San Juan Basin	E0709002-093	Bottom Ash	42.7	17.7	0.87	0.1	291	0.99	11	95.5	35.5
Wyoming	Powder River Basin	07017064	Bottom Ash	77.3	10.1	0.84	1.28	2560	0.213	9.06	347	152
Wyoming	Powder River Basin	07017065	Bottom Ash	74.8	9.48	0.807	0.909	2590	0.159	9.06	333	125
Wyoming	Powder River Basin	07017066	Bottom Ash	86.7	10.2	0.773	0.863	2570	0.128	8.92	324	74
Wyoming	Powder River Basin	07017067	Bottom Ash	82.5	9.52	0.741	0.969	2510	0.126	8.78	313	61.9
Wyoming	Powder River Basin	07017068	Bottom Ash	65.3	10.5	0.811	0.357	2470	0.21	9.43	348	104
Wyoming	Powder River Basin	07017069	Bottom Ash	74.1	7.73	0.687	0.1	2560	0.196	9.48	328	69.7
Wyoming	Powder River Basin	07017070	Bottom Ash	77.8	10.3	0.78	0.329	2410	0.163	9.21	306	86.6
Wyoming	Powder River Basin	07017071	Bottom Ash	66.7	7.59	0.568	0.395	2490	0.102	9.55	290	53.3
Wyoming	Powder River Basin	07017072	Bottom Ash	255	9.95	0.786	0.169	2560	0.129	8.82	279	99.7
Wyoming	Powder River Basin	07017073	Bottom Ash	68.9	9.69	1.05	0.312	2660	0.179	9.16	584	87.9
Wyoming	Powder River Basin	07017074	Bottom Ash	101	8.65	0.673	1.06	2570	0.185	8.44	538	125
Wyoming	Powder River Basin	07017075	Bottom Ash	92.1	7.65	0.569	0.701	2680	0.133	8.49	501	51.7
Wyoming	Powder River Basin	07017076	Bottom Ash	143	8.56	0.648	0.195	2560	0.111	8.91	548	58
Wyoming	Powder River Basin	07017077	Bottom Ash	72.1	8.85	0.642	0.699	2530	0.294	8.49	540	53.5
Wyoming	Powder River Basin	07017078	Bottom Ash	71.3	10.2	0.812	0.36	2370	0.157	8.95	591	71.6
Ohio	Appalachian Basin	07018016	Bottom Ash	214	15.4	3.2	0.24	626	0.563	7.08	221	72.9
Ohio	Appalachian Basin	07018017	Bottom Ash	201	14.7	2.08	0.14	577	0.484	5.27	192	60.5
Ohio	Appalachian Basin	07018018	Bottom Ash	208	14.5	1.12	0.1	570	0.552	5.6	206	60.8
Ohio	Appalachian Basin	07018019	Bottom Ash	194	15	1.02	0.1	568	0.588	5.84	202	61.3
Ohio	Appalachian Basin	07018020	Bottom Ash	212	19.2	1.22	0.1	589	0.55	5.62	211	61.3
Ohio	Appalachian Basin	07018021	Bottom Ash	199	16.4	1.03	0.1	588	0.598	5.46	202	57.7
Ohio	Appalachian Basin	07018022	Bottom Ash	162	22.2	1.32	0.301	554	0.611	5.52	196	63.1
Ohio	Appalachian Basin	07018023	Bottom Ash	219	40	1.92	0.755	562	0.684	5.63	207	62.9
Ohio	Appalachian Basin	07018024	Bottom Ash	216	14.6	0.963	0.1	636	0.534	6.14	221	62.1
Ohio	Appalachian Basin	07018025	Bottom Ash	185	14.8	0.922	0.129	621	0.544	6.03	215	61.5
Ohio	Appalachian Basin	07018026	Bottom Ash	216	16.4	0.916	0.1	628	0.518	5.64	213	61.2
Ohio	Appalachian Basin	07018027	Bottom Ash	240	14	0.87	ND	615	0.446	5.82	218	56.9
Ohio	Appalachian Basin	07018028	Bottom Ash	207	14.4	0.867	0.1	630	0.542	5.59	214	58.7
Ohio	Appalachian Basin	07018029	Bottom Ash	185	16.2	0.991	0.187	629	0.552	5.72	219	60.7
Ohio	Appalachian Basin	07018030	Bottom Ash	177	13.9	0.898	0.144	623	0.544	5.33	201	55.9

Notes:
Data from USGS, 2011.
RSL - USEPA Regional Screening Level (USEPA, 2012).
ppm - part per million - milligram per kilogram = mg/kg.

Supplement A

CCP Data Summary Tables from USGS, 2001

Supplement B

USEPA RSL Equations for Residential Soil Exposure

Supplement C

ProUCL Output