Chemical Constituents in Coal Combustion Residues: Risks and Toxicological Updates

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KEYWORDS: CCR health risk, toxicology, arsenic

ABSTRACT

In 2010, the United States Environmental Protection Agency (US EPA) finalized an assessment of the human health risks associated with chemical constituents in coal combustion residues (CCRs), focusing on exposure to inorganic compounds *via* the drinking water pathway. This presentation reviews some of the key results of that assessment and how that information was used in the cost-benefit analysis to distinguish among different regulatory options. Overall, the risk assessment indicated that several CCR constituents were associated with an elevated non-cancer risk under certain disposal scenarios, including antimony, molybdenum, thallium, lead, cadmium, and cobalt. The most significant risk driver, however, was arsenic, which was above cancer risk targets for several different waste management scenarios; these arsenic results formed the basis for US EPA's Regulatory Impact Analysis (RIA). Focusing on these constituents of concern, I will also provide a summary of key toxicological developments that may impact future risk assessments. Specifically, I will review recent or expected changes to the Integrated Risk Information System (IRIS) database, which contains toxicity information that is used as a basis for developing health-based regulations and remediation targets, for selected CCR constituents. In particular, I will highlight proposed changes to the criteria used to assess arsenic cancer risk, and the implications of those changes for the electric power industry.

1 INTRODUCTION

Over the past 15 years, the United States Environmental Protection Agency (US EPA) has released several different risk assessments to evaluate the potential human and ecological health risks associated with the storage of coal combustion residues (CCRs). In 1998, US EPA found that risks from non-groundwater pathways (soil ingestion, inhalation, gardening, beef and dairy, erosion, and overland transport) did not pose a significant risk, but determined that further evaluation of potential risks resulting from CCR constituent leaching to groundwater was warranted.[1] After screening out chemicals that were highly unlikely to pose a risk,[2] in 2007 US EPA released a draft risk assessment evaluating both the human and ecological effects from groundwater pathways for key CCR constituents.[3] In response to a Science Advisory Board (SAB) panel and public comments, this same risk assessment was updated and re-released in 2010 (still in draft form).[4] Also, in 2010, US EPA released a risk assessment examining potential human health risks from landfill fugitive dust.[5]

In general, US EPA's risk assessment activities are being conducted to better inform regulatory decisions regarding the disposal of CCRs. Specifically, these risk assessments are being used to evaluate whether regulating CCRs as hazardous waste under the Resource Conservation and Recovery Act (RCRA) subtitle C is appropriate. The following sections provide an overview of the results of the human health risk assessments and how this information was used to evaluate the costs and benefits of various regulatory options. Additionally, because toxicological criteria (*i.e.*, quantitative expressions of chemical toxicity) developed by US EPA for the Integrated Risk Information System (IRIS) underlie the risk estimates for CCR disposal, recent toxicological and regulatory developments related to CCR constituents will be highlighted. Understanding how US EPA's interpretation of chemical toxicity and regulatory implementation develops over time is important for the future evaluation of potential human health effects associated with both CCR disposal and beneficial uses.

2 OVERVIEW OF US EPA'S 2010 RISK ASSESSMENT

Below is a brief discussion of the key human health findings of US EPA's CCR 2010 risk assessment.[4] As noted above, the risk assessment was focused on potential risks from the leaching of CCR constituents to groundwater. This involved an investigation into both drinking water risk from the consumption of groundwater and risks from the ingestion of fish (from the movement of CCRs though groundwater into surface water and then into fish). Chemicals that exceeded risk targets at the 50th and 90th percentiles are presented in Table 1 (other compounds that did not exceed risk targets are not included in the table). A chemical exceeded the risk target if the risk exceeded 1×10^{-5} for cancer-causing agents or if the non-cancer risk (or hazard index) exceeded 1 for agents that are associated with non-cancer effects. In Table, 1 the highest hazard index or cancer risk calculated for each chemical and the associated disposal scenario is noted in parentheses.

Table 1
Risks for the Groundwater to Drinking Water Pathway

Landfills		
	Risk	
	50th Percentile Risk	90th Percentile Risk
Arsenic (III)	**2 x 10^{-5} (cancer)** (Unlined, co-disposed CCR and coal refuse)	**5 x 10^{-4} (cancer)** (Unlined, co-disposed CCR and coal refuse)
Arsenic (V)	No elevated risk	**5 x 10^{-4} (cancer)** (Unlined, co-disposed CCR and coal refuse)
Antimony	No elevated risk	**3 (non-cancer)** (Clay-lined, fluidized bed combustion [FBC] waste)
Molybdenum	No elevated risk	**2 (non-cancer)** (Unlined, conventional CCRs and co-disposed CCRs and coal refuse)
Thallium	No elevated risk	**4 (non-cancer)** (Clay-lined, FBC waste)
Surface Impoundments		
	Risk	
	50th Percentile Risk	90th Percentile Risk
Arsenic (III)	**1 x 10^{-4} (cancer)** (Unlined, co-disposed CCR and coal refuse)	**2 x 10^{-2} (cancer)** (Unlined, co-disposed CCR and coal refuse)
Arsenic (V)	**2 x 10^{-5} (cancer)** (Unlined, co-disposed CCR and coal refuse)	**2 x 10^{-2} (cancer)** (Unlined, co-disposed CCR and coal refuse)
Boron	No elevated risk	**7 (non-cancer)** (Unlined, conventional CCRs)
Lead	No elevated risk	**9 (non-cancer)** (Unlined, co-disposed CCR and coal refuse)
Molybdenum	No elevated risk	**8 (non-cancer)** (Unlined, conventional CCRs)
Nitrate/nitrite	No elevated risk	**20 (non-cancer)** (Unlined, conventional CCRs)
Selenium (VI)	No elevated risk	**2 (non-cancer)** (Unlined, conventional CCRs)
Cadmium	No elevated risk	**9 (non-cancer)** (Unlined, co-disposed CCR and coal refuse)
Cobalt	**20 (non-cancer)** (Unlined, co-disposed CCR and coal refuse)	**500 (non-cancer)** (Unlined, co-disposed CCR and coal refuse)

Table 2
Risks for the Groundwater to Surface Water Pathway (Fish Ingestion)

Surface Impoundments		
	Risk	
	50th Percentile Risk	90th Percentile Risk
Arsenic (III)	No elevated risk	**3 x 10^{-5} (cancer)** (Unlined, co-disposed CCR and coal refuse)
Arsenic (V)	No elevated risk	**2 x 10^{-5}(cancer)** (Unlined, co-disposed CCR and coal refuse)
Selenium (VI)	No elevated risk	**2 (non-cancer)** (Unlined, conventional CCRs)

By design, the US EPA CCR risk assessment attempted to calculate overall risks from CCR disposal for the utility industry as a whole. Thus, results reflect a characterization of the risks associated with a range of possible waste types and constituent concentrations across a variety of hydrogeological conditions and receptor characteristics. The value of a broad analysis is limited, given the geographic diversity of power plants, the large amount of data available for individual CCR sites, and the emergence of tools that lend themselves to better risk-based decision making on a regional or site-specific basis. It must therefore be emphasized that the risk results do not reflect the actual risk at any particular plant.

Because US EPA's modeling approach encompasses a vast number of variables, the estimation of risk, which involves various assumptions about constituent fate and transport, as well as toxicity and receptor exposure, by necessity, requires considerable simplification. These simplifications often lead to a considerable of uncertainty with the assessment. Additionally, where uncertainty exists, in many cases, conservative approaches were used that tend to overestimate rather than underestimate risk. Although it is beyond the scope of this paper to detail the many specific uncertainties associated with the risks presented in Table 1 and 2, some key uncertainties – particularly those that may have lead to an overestimate of risk – include:

- Use of a 10,000-year modeling period (complete leaching, long timeframe);
- Well locations;
- Sorbents used to determine partition coefficient (Kd) values;
- Analysis of leachate data;
- Characterization of high-end receptor exposure factors; and
- Human health benchmarks.

3 USE OF HUMAN HEALTH RISK ASSESSMENT DATA IN THE REGULATORY IMPACT ANALYSIS

To evaluate the cost-benefit of different regulatory options, US EPA conducted an analysis, in which benefits, in part, were based on a reduction in potential cancer cases associated with different waste management options.[6] Avoided remediation costs from mismanaged impoundments and landfills (chronic problems and catastrophic failures) were also considered. Both the analysis of cancer cases avoided as well as reduced remediation costs were developed using health-based information, and, specifically, were developed using the arsenic cancer risks estimated in the CCR risk assessment (See Tables 1 and 2) above.[*] Some key features of each of these analyses related to health-based information are presented below:

Analysis of Cancer Cases Avoided

To quantify the number of cancer cases that could be avoided under different regulatory options, US EPA conducted a population risk assessment. In general, this involved determining the number of individuals that could be potentially exposed to CCR constituents in drinking water from groundwater use and using the risk estimates developed in the 2010 CCR risk assessment to determine the potential number of excess cancer cases resulting from this exposure. This analysis was complex and involved several steps, with several key uncertainties that are not reviewed here.

Instead, this paper will focus on how the 2010 CCR risk assessment results were used to calculate the potential excess cancer cases in the absence of any regulation. US EPA used two estimates of cancer potency to calculate the number of potential excess cancer cases. Estimates of cancer potential are called cancer slope factors CSFs). US EPA's first determination used the same CSF that was used in the risk assessment—specifically, the current CSF of 1.5 $(mg/kg\text{-}d)^{-1}$ that is currently posted in the IRIS database. However, US EPA also used the more recent analysis of arsenic cancer potential developed by the National Research Council (NRC) of 26 $(mg/kg\text{-}d)^{-1}$.[7] Using the IRIS CSF yielded a weighted average of 145 cancers over a 75-year period, while the NRC CSF yielded a weighted average of 2,509[†] cancers over a 75-year period. Both estimates assumed no remediation of CCR-related contamination over the next 75 years.

As explained in more detail in Section 3, the CSF developed by the NRC in 2001 has not gained regulatory acceptance, and, in fact, there are more recent analyses of the arsenic CSF. While it is widely recognized that the CSF for arsenic in IRIS is outdated, and it is more scientifically sound to assess arsenic's carcinogenic potency on bladder and lung cancer as opposed to skin cancer, the methodology used to derive CSFs is the source of unresolved scientific debate. The arsenic CSF, reported in IRIS, is currently being reviewed by US EPA and by scientific advisory panels. There are several

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[*] Cancer cases avoided were based only on arsenic risks, likely because arsenic was the key risk driver. Also, the risks associated with the groundwater to drinking water pathway were considered exclusively (fish ingestion was not evaluated).

[†] There is a typo in Exhibit 5A-7 of the RIA. The only way to obtain a weighted average of 2,509 cancers is if the total cancers for Unlined Surface Impoundments is 2,885, not 2,865. (Using a value of 2,865 results in a weighted average of 2,496 cancers.)

outstanding scientific issues, many of which relate to assumptions used by NRC to develop the CSF in 2001. Until the CSF assessment is finalized, it is not appropriate to use a value that lacks a scientific consensus.

Regardless of the actual value used, it is important to appreciate that both CSFs are derived using health-protective assumptions that overestimate risks (and cancer cases, in this case). For example, slope factors are derived using linear extrapolation (usually based on the lower confidence interval of the dose-response function). These conservatisms built into the CSF are more appropriate for calculating worst-case individual risk estimates rather than for estimating population risks and estimates of expected excess cancer cases.

After calculating the number of potential excess cancer cases in the absence of any remediation using both CSFs, US EPA calculated excess cases considering both the effectiveness of existing state regulations in indentifying remediation and initiating cleanup and that a more stringent regulatory environment in the future (*i.e.*, regulation under different regulatory options) would lead to better compliance. More stringent regulation, in turn, would lead to more prompt cleanup (*i.e.*, remediation) and more cancer cases avoided. An important assumption in the RIA, however, was that all facilities would eventually identify contamination and initiate remediation; in a less stringent regulatory environment, again, the assumption was that detecting the contamination would just take longer. This analysis was performed only using the NRC CSF. A summary of the results of this approach above is presented in Table 3.

Table 3
US EPA's Analysis of Cancer Cases Avoided

Scenario	**# of Potential Excess Cancer Cases over 75 years**
Using the IRIS CSF, not considering any remediation	145
Using the NRC CSF, not considering any remediation	2,509
Using the NRC CSF, considering baseline regulations that will detect contamination and initiate remediation because cancer cases occur	726
Using the NRC CSF, under subtitle C (*i.e.*, all contamination will be detected and remediated before causing any excess cancer cases)	0 (726 avoided)
Using the NRC CSF, under subtitle D (*i.e.*, some contamination will be detected and remediated before causing any excess cancer cases, but detection will take longer)	430 (296 avoided)

Analysis of Remediation Costs Avoided

US EPA also used the results of the 2010 risk assessment to estimate remediation costs associated with constituents leaching from WMUs. Like the cancer cases avoided analysis, the remediation assessment only considered costs associated with the cleanup of arsenic. Similar in concept to the cancer cases avoided analysis, in estimating monetized benefit associated with remediation, US EPA assumed that the earlier a plume is detected, the lower the groundwater remediation costs. Thus, the more stringent the regulation, the greater the remediation costs avoided. The remediation costs avoided were calculated by subtracting the remediation costs under each option from the baseline remediation costs. To estimate the baseline cost, US EPA estimated the number of coal-fired electric utility plants that could require remedial responses based on the risks calculated in the risk assessment. Specifically, US EPA calculated the number of facilities that were associated with cancer risks above 10^{-4}, 10^{-5}, and 10^{-6}.

A number of simplifying assumptions can cause the remediation costs analysis to be uncertain, including a single generic remediation cost, how the costs relate to the time-to-detection, and whether regulatory compliance is a good proxy remediation expenses. With regard to how information from the risk assessment was used (which is the focus of this analysis), as explained above, costs were related to the number of plants that would remediate arsenic-contaminated groundwater associated at different risk levels. However, arsenic is a naturally occurring compound, and, using the current IRIS slope factor, typical concentrations of arsenic in drinking water would be associated with an approximately 5×10^{-5} cancer risk.[8] It is therefore inappropriate to assume that plants would engage in cleanup activities when arsenic risks in drinking water were 1×10^{-5} or less because this could involve cleaning up arsenic to below background.

4 TOXICOLOGICAL AND REGULATORY UPDATES

As highlighted in the sections above, quantitative toxicity information plays an important role in the risk interpretation of CCRs and, consequently, in regulation of CCR disposal and the evaluation of safe beneficial uses. As the risk assessment of CCRs continues to develop, new toxicological information (or a change in interpretation of existing toxicological information) is also developing. As a result, many of the key CCR constituents are undergoing re-evaluation by US EPA for inclusion in IRIS. A summary of some recent chemical evaluations and their implications for the risk assessment of CCRs is presented below.

Arsenic: As mentioned in the discussion of the cost-benefit analysis, the carcinogenic potency of inorganic arsenic is under review. Revisions to estimates of arsenic's cancer potency have been ongoing for many years. In late 2010, a draft IRIS report established a cancer potency for arsenic that 17 times more toxic than the existing value.[9] This assessment is based on bladder and lung cancer, instead of skin cancer. Several outstanding scientific issues have been raised and, at present, it is unclear when this value or an alternative will be finalized. Given that arsenic is a key risk driver for the human health evaluation of CCR disposal, a change in the CSF for arsenic will have a significant impact on risk estimates. Additionally, US EPA is also slated to issue a revised assessment on arsenic non-cancer toxicity within a few months. This also could affect the future evaluation of the risks associated with CCRs.

Hexavalent Chromium: In light of a new animal study conducted by the National Toxicology Program, US EPA has issued a draft IRIS report that classifies hexavalent chromium as "likely to be carcinogenic to humans" *via* the oral route of exposure.[10] As with inorganic arsenic, there are several outstanding scientific issues related to the assessment, and it is unclear when or if ever the currently proposed CSF of 0.5 mg/kg-d will ever be finalized. While the non-cancer effects of chromium were evaluated in the 2010 CCR risk assessment (and found to be associated with minimal risk), the potential oral carcinogenicity of hexavalent chromium was never assessed. Including an evaluation of the hexavalent chromium carcinogenicity could have a significant effect on the interpretation of the risks associated with CCRs. The non-cancer criteria of hexavalent chromium were also evaluated and resulted in a Reference Dose (RfD) about 3-fold lower than the value currently published on IRIS.

Cobalt: In the 2007 draft US EPA CCR risk assessment, cobalt risks were calculated using an RfD of 2×10^{-2} mg/kg-d. This value was not published on IRIS, but was developed by the Superfund Technical Support Center under the National Center for Environmental Assessment (NCEA) for use in risk assessment. Since this value was first developed (in 2001), it has been withdrawn. In 2008, NCEA re-evaluated cobalt toxicity and established an RfD of 3×10^{-4} mg/kg-d, a value about 67 times lower (*i.e.*, more stringent) than the previous value.[11] At this same time, NCEA also updated the inhalation reference concentration (non-cancer) and the inhalation unit risk (cancer) for cobalt.

The change in the oral RfD for cobalt between the 2007 and 2010 CCR risk assessments, caused the cobalt risks to increase from 8 to 500 at the 90th percentile for co-disposed CCR and coal refuse in unlined surface impoundments. IRIS is currently in the process of developing toxicity criteria for cobalt, with a final assessment not expected until at least late 2012. The IRIS value, which will undergo a more rigorous scientific review process than the values developed under NCEA for the Superfund program, will take precedence over the NCEA value for evaluating the human health risks associated with CCRs when finalized.

Thallium: Thallium risks did not differ between the 2007 and 2010 CCR risk assessment, but, during the time period between the two assessments, IRIS re-evaluated and withdrew the then-existing RfD for thallium of 8×10^{-5} mg/kg-d, concluding that the underlying toxicity data had too many limitations to derive a reliable value.[12] However, in the absence of any other quantitative information on thallium's toxicity, the 2010 CCR risk assessment defaulted to the older thallium value that had been listed under IRIS, even though this value was determined to be uncertain. Interestingly, in the absence of a quantitative value in IRIS, in 2010, NCEA evaluated oral thallium toxicity. While NCEA agreed the underlying toxicity data was poor, it did use existing information on thallium to establish a "screening value," that "may be useful in certain instances."[13] This screening value was based on a provisional RfD of 1×10^{-5}

mg/kg-d (which is eight times lower than the value that was withdrawn from IRIS). Although uncertainty in this value is repeatedly acknowledged by NCEA, this "screening" RfD will likely be used in future risk assessments, including those evaluating the human health risks associated with CCR disposal and beneficial use.

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