A National Analysis of Toxic Releases from Electric Power Plants

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INTRODUCTION

Since 1998, electric utility companies burning coal or oil have been required to report their annual releases of toxic chemicals to the Toxics Release Inventory (TRI), a national compilation of multimedia (air, water, and land) releases of more than 600 chemicals and chemical categories designated as toxic by the U.S. Environmental Protection Agency (EPA). An analysis of the TRI indicates that reportable toxic releases from the electric utility industry will exceed those of any of the manufacturing industries currently reporting to the TRI. Thus, the addition of power plants to the TRI will significantly change the rankings of chemicals, industries, and facilities identified in the annual TRI report. The implications of these changes are discussed with regard to risk communication needs and pollution prevention measures potentially available to reduce toxic releases from power plants.

BACKGROUND

TRI is a publicly available database established to provide information on the presence and releases of toxic chemicals in U.S. communities. The TRI was established by Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986, and was expanded by the Pollution Prevention Act of 1990. The law requires facilities in designated industry sectors to report annually the amounts of toxic chemicals released to the environment, along with information on waste management and pollution prevention activities. More than 600 chemicals and chemical categories are included on the current TRI list. Published annually by EPA and available on the World Wide Web, the TRI has become an important vehicle for identifying and quantifying the mass of chemicals released by industries and facilities at the local, state, and national levels. However, the TRI currently provides no information on the relative toxicity or risks from the releases that are reported.

Since the TRI was established in 1986, the industries required to report toxic emissions have included only the 20 major manufacturing industries identified by Standard Industrial Classification (SIC) codes 20-39. In May 1997, EPA added seven new industry groups to the TRI, including oil and coal-burning electric power plants.[1] Affected facilities in these industries must report TRI emissions on an annual basis, beginning with 1998 emissions. Reports for 1998 were to be filed with EPA by July 1, 1999. In the past, EPA has needed approximately one year to compile, analyze, and publish the results, although the TRI for 1998 is expected to be available within a shorter time frame.

To obtain some perspective on the importance of the electric power sector relative to other reporting industries, this article presents a historical analysis of state-level and national estimates of TRI emissions. Nationally, the chemicals industry (SIC 28) and the primary metals industry (SIC 33) have had the largest total releases, as seen in Table 1. Methanol, ammonia, and zinc compounds have been the TRI chemicals emitted in greatest quantity, as shown in Table 2. The key question that motivates our research is how electric utility sector releases will alter the magnitude and types of chemicals reported by the TRI and the rankings of industry groups. To address this question, we derive estimates of TRI emissions from coal-fired plants in the United States for 1995 (the most recent year for which TRI data were available for other industry groups at the time this study was initiated). Since that time, TRI results for 1996 and 1997 also have been released by EPA,[2] but as seen in Tables 1 and 2, those results are similar to the inventory for 1995.[3]

TRI REQUIREMENTS

Electric utility plants covered by the TRI are in SIC codes 4911, 4931, and 4939. Any facility within a covered industry is required to report to the TRI if it has the equivalent of 10 or more fulltime employees and manufactures or processes

Table 1. Largest total releases by industry in 1995-1997 (millions of pounds per year).

SIC	Industry	1995 Releases Air	1995 Releases Total	1996 Releases Air	1996 Releases Total	1997 Releases Air	1997 Releases Total
28	Chemicals	407	844	392	785	342	797
33	Primary metals	138	524	145	565	132	695
26	Paper	213	238	204	228	194	234
30	Plastics	112	127	105	116	98	108
37	Transport equip.	109	121	103	111	91	102
	All industries	1562	2531	1452	2434	1332	2578

Source: References 2 and 3. Figures include both on-site and off-site releases to air, water, and land.

Table 2. Largest total releases by chemical in 1995-1997 (millions of pounds per year).

Chemical	1995 Releases Air	1995 Releases Total	1996 Releases Air	1996 Releases Total	1997 Releases Air	1997 Releases Total
Methanol	210	255	206	241	194	221
Ammonia	157	195	155	193	156	200
Zinc compounds	5	189	6	207	5	306
Toluene	145	147	125	127	113	116
Nitrate compounds	<1	145	<1	164	<1	197
All chemicals	1562	2531	1452	2434	1332	2578

Source: References 2 and 3. Figures include both on-site and off-site releases to air, water, and land.

more than 25,000 lbs of any listed toxic chemical during the reporting year or otherwise uses more than 10,000 lbs of any listed chemical. Trace chemicals in air and water intake streams are excluded from TRI reporting. The TRI also exempts toxic chemicals that appear in low concentrations in products that are distributed in commerce. Thus, a power plant that sells a byproduct such as fly ash or gypsum containing TRI chemicals maybe able to apply the de minimus exemption to that byproduct stream. If the concentration limit is not exceeded—as is typically the case for power plant byproducts—the quantity of chemicals in the byproduct would be exempt from TRI reporting.

For most power plants, the most relevant set of TRI chemicals are those designated as manufactured or otherwise used.[4] These include the trace organics that may be found in some combustion flue gas streams, plus certain metal oxides present in fly ash, bottom ash, stack emissions, and flue gas desulfurization (FGD) wastes. Other inorganic TRI chemicals of importance are hydrochloric acid (HCl), hydrogen fluoride (HF), and sulfuric acid (H_2SO_4) aerosol, which is defined by EPA to include gases and vapors as well as mixtures of gases and particles.[1] A more detailed discussion of TRI requirements for electric power plants can be found in reference 4.

ESTIMATING NATIONAL RELEASES

This section summarizes the methods used to estimate toxic chemical releases from electric power plants. The TRI offers substantial latitude in the methods that facilities can use to estimate toxic releases in the absence of site-specific data. Therefore, the "base case" approach used in this study assumes that utilities will tend to use methods and assumptions that minimize estimated emissions in cases where there are reasonable uncertainties as to the best or most appropriate estimation method. Subsequently, we attempt to bound these base case estimates by developing an "upper bound" scenario that reflects more conservative assumptions.

Data Sources and Assumptions

The approach used is this study is a "bottom up" analysis that estimates toxic releases from every generating unit in the country, then aggregates results to the plant, state, and national levels. The data sources and assumptions used for our estimates are summarized below.

Coal Use and Power Plant Data. Power plant and fuel use data were taken from the 1995 Form 423 submitted by fossil-fuel burning power plants to the U.S. Federal Energy Regulatory Commission (FERC). The forms are submitted monthly and list the cost and quality of fossil fuels delivered to electric generating plants. The data are then merged into a large public database.[5]

All coal-fired generating units with a gross electric capacity of 50 megawatts (MW) or more are considered in this study. Units smaller than 50 MW are excluded because FERC data do not clearly distinguish the amounts of different fuels used. Because most power plants contain multiple units, the fuel use and capacities of all units at a given facility are aggregated to determine whether TRI thresholds have been exceeded. Figure 1 shows the distribution of plant sizes modeled in this study.

The fuel source information for each facility includes the type, rank, county, state, supplier, quantity, energy content, sulfur content, and ash content of fuel on an as-received basis. Table 3 shows the total coal purchased for 1995, which is assumed to equal the amount burned. For comparison, utility coal consumption for 1995-1998 is also shown in Table 3.

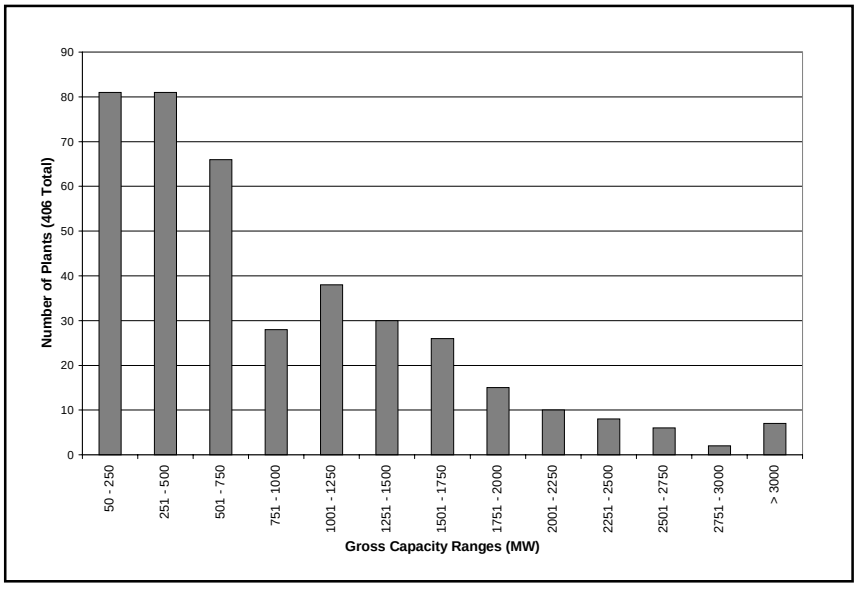

Figure 1. Size distribution of coal-fired power plants modeled in this study (from 1995 FERC 423 data)

Net electricity generation from coal increased from 1653 billion kilowatt hours (BkWh) in 1995 to 1807 BkWh in 1998.[6]

Oil-Fired Plants. Although oil-fired power plants are covered by the TRT, they are omitted in the present study because a scoping analysis indicated that their contribution to total national releases is small. To the extent that some oil-fired plants do contribute to the TRI (principally HCl, H_2SO_4, and nickel compounds), the current estimates for coal plants may be viewed as a lower bound for the utility sector as a whole.

Trace Element Concentrations and Emission Factors. In addition to plant-level data on annual coal consumption and sulfur content, the trace element concentration of coals burned is required to calculate TRI thresholds and chemical releases. This study employs trace element concentration data compiled by Radian International for the Electric Power Research Institute (EPRI).[7] The data reflect information from a literature survey plus field tests by EPRI,[8] the U.S. Department of Energy (DOE),[9] and others. Table 4 shows the median values for the chemical concentrations in coal averaged across the six coal supply regions used in this study. These data reflect coal actually used by utilities as opposed to coal in the ground. Because chemical concentrations are given on a dry basis, coal moisture content also must be specified to calculate chemical releases for the TRI.

Trace Element Partitioning Data. The partitioning of trace chemicals between air and solids was estimated using data in the PISCES Model,[10] a mass and energy balance model developed for EPRI to quantify multimedia chemical releases from power plants.[4] The data sources used in the PISCES Model are the same as those noted earlier.[7-9]

Otherwise Used Chemicals. Our study does not include any chemicals that are "otherwise used," because such amounts are highly site-specific and not easily estimated. A previous case study[4] suggests these amounts are likely to be small relative to the amounts that are "coincidentally manufactured" in the combustion process.

Particulate Collector Performance. Because of site-specific data limitations on particulate collector type and emission rates,

Table 3. Summary of power plant coal consumption (million tons/yr).

FERC 423 Database[a]		DOE/EIA[b]			
Coal Rank	**1995**	**1995**	**1996**	**1997**	**1998**
Bituminous	419				
Subbituminous	330				
Lignite	75				
Total	**823**	**829**	**875**	**899**	**911**

[a]From reference 5. [b]From reference 6.

Table 4. Mass concentrations of trace chemicals in coal (ppmw, dry basis).[a]

Chemical	Bit	Subbit	Lig
Antimony	1.0	0.57	0.74
Arsenic	10.0	5.9	8.5
Barium	94.5	196.	220.
Beryllium	1.3	0.5	1.9
Cadmium	0.53	0.83	0.1
Chloride	750.	195.	140.
Chromium	18.6	5.0	9.3
Cobalt	6.4	2.0	3.7
Copper	21.	9.3	10.5
Fluoride	69.	44.	79.
Lead	8.1	7.8	6.2
Manganese	22.4	35.5	74.
Mercury	0.12	0.10	0.22
Molybdenum	2.1	1.7	3.0
Nickel	16.1	9.5	5.9
Selenium	3.2	0.9	1.3
Silver	0.2	0.16	0.1
Thallium	1.6	2.0	0.5
Zinc	22.0	8.7	7.8

[a]From references 7 and 10. Values for each coal rank are the median values across coal supply regions. Moisture content across regions is 5.2-10.5% (bit), 9.0-28.5% (sub), and 35.0-36.5% (lig).

an electrostatic precipitator (ESP) is assumed for all power plants, and all particulate emission rates are assumed to comply with federal New Source Performance Standards (NSPS). This assumption determines the ESP trace chemical partitioning (removal efficiency) data obtained from the PISCES Model for each coal rank. Median values are used for all plant-level estimates.

Sulfuric Acid Aerosol. One of the most poorly understood aspects of power plant toxic releases is the magnitude of H_2SO_4 vapor and aerosol formed and removed within power plant systems. Because H_2SO_4 aerosol is not listed by EPA as a hazardous air pollutant (HAP), none of the recent field sampling programs conducted by EPRI or DOE included H_2SO_4 emissions in their testing. Utilities do not commonly measure H_2SO_4 emission rates or removal efficiencies either. The existing technical literature and data on this subject display a very large uncertainty, ranging up to two orders of magnitude in emission estimates. Table 5 summarizes the range of assumptions used in this article, drawn from EPA and industry sources.[10-12]

FGD System Performance. Where the presence of an FGD system is indicated in FERC 423, a wet lime/limestone system is assumed. The median value of TRI chemical concentrations in lime and limestone reagent[10] are used as additional process inputs. The median value of trace chemical removal efficiency across an FGD system (based on all fuel ranks) is also obtained from the PISCES Model.[10]

Solid Waste Management. Power plants use either wet or dry ash handling systems to manage solid wastes. For plants using wet systems, some of the trace substances in the collected solids are transferred to the sluice water, and some of that amount may be released to the environment via the plant water treatment system. Because of data limitations, TRI water releases are difficult to quantify, though limited case studies suggest they are a small percentage of the total in collected solids.[4] The present study, therefore, reports only air and total releases, recognizing that the difference is predominantly disposal to land. These land releases may occur either on- or off-site. The TPI considers any type of landfill disposal to be a release. Exempt from TRI reporting are chemicals contained in power plant byproducts distributed in commerce. These quantities were estimated based on national average percentages for 1995, which were 33.3% for bottom ash, 25.0% for fly ash, and 7.4% for FGD material.[13]

Table 5. Assumptions for sulfuric acid emissions.

Coal Type	wt% SO_x as SO_3[a]
Base Case[b]	
Western bituminous	0.05
All other bituminous	0.4
PRB sub-bituminous	0.01
All other sub-bituminous	0.1
All lignite	0.1
Bounding Case[c]	
All coals	0.7

[a]All SO_3 is assumed to convert to H_2SO_4.
[b]Based on reference 11. FGD removal assumed to be 65% (reference 10).
[c]From reference 12. FGD removal assumed to be 50% (reference 12).

Study Methodology

Figure 2 shows a schematic of the procedures used to estimate national TRI releases. The aggregated data for each facility included the total annual coal use and the relative percentages of coal from each supply region. These percentages were applied to the trace element coal concentrations for each coal supply region and coal rank to determine the total quantity of trace chemicals manufactured during combustion. This is the principal quantity determining whether the TRI threshold is exceeded. For plants with FGD systems, the trace chemicals in the FGD reagent also were assumed to undergo coincidental manufacture.

The TRI threshold test was applied to each trace chemical. If the threshold

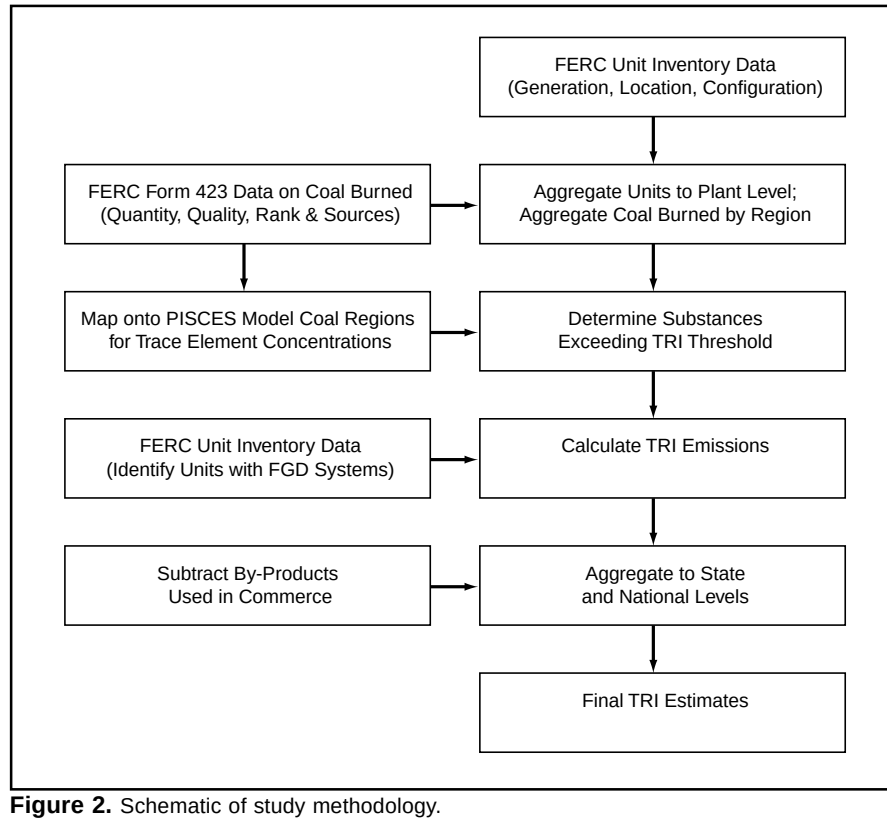

Figure 2. Schematic of study methodology.

was exceeded, the partitioning of each trace chemical between air and solids was calculated for each plant using empirically determined removal efficiencies across the boiler, ESP and FGD system.[10] Reportable releases excluded the percentages of trace metal in collected solids distributed in commerce. The final results were then aggregated to the state and national levels.

Study Results

Table 6 summarizes the total estimated releases of reportable TRI chemicals for 1995 using the base case assumptions. HCl aerosol is the major TRI chemical produced by electric power plants, accounting for 56% of the total utility releases nationally. Combined land and water releases (most of which are landfilled solids) amount to 25% of the national total for power plants. Overall, 17 TRI chemicals exceeded the reporting threshold at one or more facilities. Note, however, that no releases of mercury are included in this inventory. Although mercury emissions have been highlighted by EPA as perhaps the major air toxic of concern for power plants, mercury emissions from an average-sized plant are two orders of magnitude below the TRI reporting threshold. Beginning in 2000, however, EPA plans to lower the TRI thresholds for certain persistent, bioaccumulative toxic chemicals. For mercury the proposed new threshold would be 10 lbs/yr rather than 25,000 lbs/yr.

The total mass of 987 million pounds of power plant releases for 1995 (Table 6) is larger in magnitude than the total releases of any of the manufacturing industries shown earlier in Table 1. This means that on the basis of total mass emissions, power plants would have surpassed the chemicals industry as the largest source of toxic releases nationally in 1995. Ohio had the largest power plant releases of any state (Figure 3), with 10 states accounting for 63% of the total utility releases. HCl aerosol replaced methanol as the chemical released nationally in greatest quantity when utility emissions were included. In 17 states (see Figure 3), a coal-fired power plant would have been listed by EPA as having the largest total releases in the state.[14] The actual 1995 TRI listed Texas, Louisiana, and Ohio as the states with the largest toxic releases. Had power plants been included, the top three states would have been Texas, Ohio, and Pennsylvania.

Uncertainty Analysis

There is substantial uncertainty in any estimate of toxic releases from power plants.[15] Thus, we attempted to bound the TRI estimates in Table 6 by examining the sensitivity of those results to key assumptions affecting the largest releases. For HCl and HF a bounding estimate was obtained using the EPA emission factors provided in the utility industry TRI guidance document.[16] Use of the EPA factors doubled the base case estimates in Table 6.

Uncertainty in H_2SO_4 aerosol releases stems from uncertainty in the fraction of fuel sulfur converted to SO_3 and subsequently released as H_2SO_4 (which is produced in the flue gas train by reaction with water vapor). Production levels of SO_3 are known to depend upon plant parameters such as boiler type and excess oxygen levels, while emission levels (as H_2SO_4) also depend upon coal ash composition, air preheater design, and air pollution control equipment. Measurement methods also may affect reported results. The base case values in Table 5 are based primarily upon a widely circulated paper by Southern Company Services.[11] Other studies, however, report much higher SO_3 levels. Nonetheless, we believe it unlikely that average H_2SO_4 emissions reported to the TRI will exceed the EPA emission factor estimate of 0.7% sulfur as SO_3. Thus, our bounding case uses this emission factor, along with a slightly lower SO_3 removal efficiency for FGD systems. These assumptions yield a national estimate of H_2SO_4 releases that is twice the base case value in Table 6.

For trace metal air releases, uncertainty estimates should consider the variability of trace element concentrations within each coal supply region, plus variations and uncertainty in the removal efficiency of particulate collectors. While a detailed analysis of these factors was not performed in this study, we estimate an emissions increase of roughly 20-30% over the base case values based on previous case studies.[4,15]

Table 7 summarizes the resulting range of TRI estimates for 1995, which vary by a factor of 2, from 990 to 1880 million pounds. When normalized on net electricity generation, the total TRI releases range from 0.6 to 1.1 lbs/MWh. Actual releases are expected to be closer to the lower (base case) value. As noted earlier, these estimates do not include otherwise used chemicals, oil-fired power plants, or coal-fired boilers less than 50 MW in size. For the power industry as a whole, the contribution of these sources was found to be small.

Table 6. Base case estimates of total power plant releases for 1995 (millions of pounds).[a]

TRI Chemical	Air	Total
HCl aerosol	553.5	553.5
Barium compounds	<0.4	142.3
H2SO4 aerosol	129.6	129.6
Hydrogen fluoride	55.4	55.4
Manganese compounds	0.2	29.3
Zinc compounds	0.2	19.2
Copper compounds	0.1	12.2
Nickel compounds	0.1	11.7
Chromium compounds	<0.1	9.9
Lead compounds	<0.1	6.8
Arsenic compounds	<0.2	6.0
Molybdenum trioxide	<0.1	4.7
Cobalt compounds	<0.1	3.6
Antimony compounds	<0.1	1.5
Selenium compounds	0.3	0.7
Thallium compounds	<0.1	0.4
Beryllium compounds	<0.1	0.3
Total	740.	987.

[a]Figures for metal compounds refer to weight of elemental metal. Totals include on-site and off-site releases.

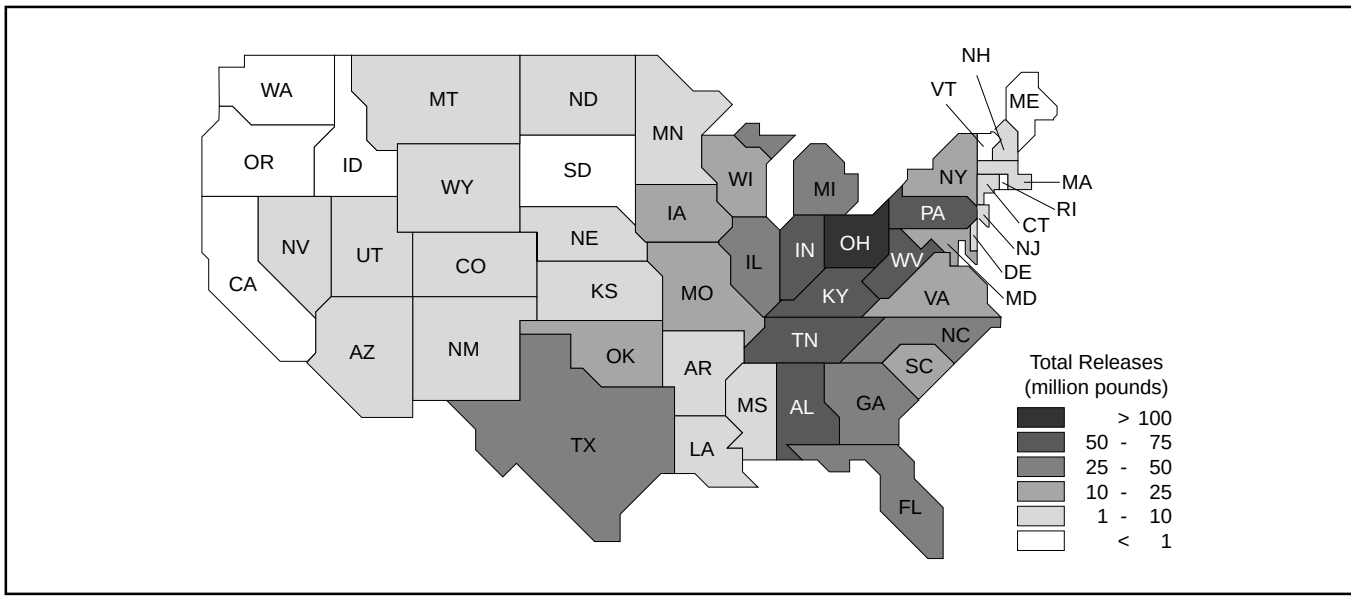

Figure 3. Base case estimates of TRI releases from coal-fired power plants for 1995. (A power plant is the largest TRI source in Arkansas, Colorado, Connecticut, Delaware, Georgia, Indiana, Kansas, Kentucky, Massachusetts, Maryland, North Dakota, Nebraska, New Hampshire, Nevada, Tennessee, Virginia, and West Virginia.)

Study Implications

The results of this analysis show that the addition of the electric utility industry to the TRI would have significantly altered the national picture of major toxic releases and their sources for 1995. The electric utility industry was found to have the largest on-site and total releases nationally, with HCl aerosol replacing methanol as the TRI chemical released in greatest quantity. Power plant releases also added to, and often dominated, the inventories of sulfuric acid aerosol, hydrogen fluoride, and various metal compounds, especially barium. In many states and communities, a local power plant would have been named by EPA as the largest emitter of toxic pollutants, rather than a local industrial plant.

What about results for 1998? In the past three years, some electric power plants have achieved additional reductions in sulfur and H_2SO_4 emission rates. Some additional FGD capacity also has helped to lower releases of H_2SO_4, HCI, HF; and other TRI chemicals. Nonetheless, in view of the 10% growth in coal use for power generation since 1995 (see Table 3), the qualitative results found for 1995 are likely to also apply to the 1998 TRI, which will report the first true estimates of power plant toxic releases. Based on the 10% increase in coal use, 1998 releases from electric utilities are likely to be in excess of 1.1 billion pounds. Releases from other newly listed industries, especially the mining industry and hazardous waste disposal sites, could rival power plant releases in some regions of the country.

By comparison, in June 1999 the Edison Electric Institute (EEI) released data on the actual 1998 TRI emissions for a large segment of U.S. utilities.[16] The EEI report included 710 million pounds of releases of six TRI chemicals from approximately 65% of all coal-fired generating capacity and 40% of oil-fired plants. HCI accounted for more than 54% of the total, H_2SO_4 for 15%, HF for 6%, and metal compounds (Ba, Mn, and Ni) for 30% of the total. These percentages are similar to our own predictions. Furthermore, a simple extrapolation of the EEI data to cover 100% of coal-fired capacity gives a total national release of 1.1 billion pounds, identical to our own rough estimate for the 1998 base case.

RISK COMMUNICATION NEEDS

Because the TRI reports only the mass of chemical releases, and is silent on issues of toxicity or community risk, both electric utilities and EPA should be actively engaged in explaining and interpreting the new inventory numbers to

Table 7. Uncertainty estimates for total 1995 releases from coal-fired power plants (millions of pounds).

Substance	Air Releases		Total Releases	
	Base[a]	Bound[b]	Base[a]	Bound[b]
HCl aerosol	553	1147	553	1147
H_2SO_4 aerosol	130	287	130	287
Hydrogen fluoride	55	135	55	135
Metal Compounds	<2	2	249	311
Total	**740**	**1541**	**987**	**1880**

[a]Base case estimates from Table 9.

[b]Upper bound estimate (see text for assumptions).

the public. Indeed, a major criticism of the TRI is that the largest mass releases are not necessarily indicative of the largest environmental concerns. For example, the metal compounds in fly ash and bottom ash, which are now labeled as toxics by the TRI, were previously designated as non-hazardous by EPA under the Resource Conservation and Recovery Act (RCRA). Similarly, HCl releases, which dominate the power plant inventory, were found by EPA to pose "no exceedance of the health benchmarks" for inhalation exposure in a recent assessment of health risks from HAPs. That same study did not consider H_2SO_4 aerosol because it is not listed by EPA as a HAP (although it is labeled as toxic under the TRI).

This potentially confusing and conflicting set of labels, perceptions, and concerns regarding power plant releases is likely to be puzzling to most citizens when the 1998 TRJ results are formally announced by EPA. The agency emphasizes the fact that environmental risks from TRI chemicals may indeed exist at the local level, and that such risks are not precluded by current regulatory designations. It is up to individual communities, however, to assess those risks. Various types of risk communication activities will therefore be important in addressing community concerns. Indeed, many utility companies already have initiated such programs. In addition, the use of toxicity weighting factors and screening risk assessments[20] are among the tools that can be helpful for putting the TRI results into perspective and establishing priorities for further study where warranted.

POLLUTION PREVENTION OPTIONS

In the near to longer term, the TRI also is likely to stimulate efforts to better quantify major power plant releases and to reduce overall emissions consistent with the pollution prevention objectives of the TRI and industry's ability to respond. Some of the available options include refinements in the methods and data used to estimate toxic releases; load management and other methods to decrease utilization of high-emission plants; switching to low-sulfur, low-chloride coals; increased use of alternative fuels such as natural gas; installing and/or upgrading pollution control equipment (especially ESPs and FGD systems); improving plant operating practices to reduce or eliminate the use of TRI chemicals (e.g., for water treatment and plant maintenance); and developing new markets for plant byproducts, including bottom ash, fly ash, and FGD wastes. The latter remains a key challenge for the research and development community as well as for electric utilities.

ACKNOWLEDGEMENTS

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