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Project Summary

Source Assessment: Dry Bottom Utility Boilers Firing Pulverized Bituminous Coal

D.G. DeAngelis, R.B. Reznick, D.S. Ruffin. J.N. Rigano,
W.R. McCurley, J.C. Ochsner, and T.W. Hughes

This project summary describes and assesses the potential impact of air emissions, wastewater effluents, and solid wastes resulting from the operation of dry bottom utility boilers firing pulverized bituminous coal. Consuming approximately 3.2 x 10^8 metric tons of such coal per year, this source-type constitutes the primary method of firing coal in utility boilers.

Air emissions were characterized from literature data supplemented by a field sampling program. Significant emissions resulting from coal combustion were particulate matter, sulfur oxides, nitrogen oxides, hydrocarbons, polycyclic organic materials, and a number of elements emitted as particles and vapors. The potential environmental impact of each emission species, after passing through state-of-the-art controls was individually assessed using a calculated quantity known as the ambient source severity. This quantity is the ratio of the maximum ground level concentration, as determined through dispersion equations, to an ambient environmental goal. No species was found to have an ambient source severity greater than 1.0; nitrogen oxides (0.97) and sulfur oxides (0.93) had the highest severities. It was estimated that the human population around an average source in this category exposed to an ambient severity greater than 0.05 was ~300,000 persons for nitrogen oxides and sulfur oxides.

Pollutant concentrations were also determined in wastewater and solid waste streams. Effluent source severities, defined as the ratio of the concentration of a pollutant in the receiving water after dilution to an ambient environmental goal, were found to be significantly less than 1.0 for most species. The potential impact of solid waste discharges on the quality of air and of ground and surface water was also found to be minor when available controls are applied.

This report, upon which this summary is based, was submitted under Contract No. 68-02-1874 by Monsanto Research Corporation under the sponsorship of the U.S. Environmental Protection Agency, and covers the period from May 1974 to August 1980.

Introduction

The purpose of this study was to characterize air emissions, water effluents, and solid residues resulting from the combustion of pulverized bituminous coal in dry botton utility boilers. The report contains a source description that defines process operations, process chemistry, plant capacity, and source locations. The multimedia emissions characterization identifies all emission points and emission species, determines their emission rates, and evaluates the potential environmental effect due to their release. Present and emerging control technologies are also considered. The final section of the report discusses the growth and nature of the source type.

A general indication of the size and position of this source type within all combustion sources is shown in Figures 1 through 3.[1,2] From Figure 1, utility combustion is the third largest consumer of fossil fuel, representing 25% of national fossil fuel consumption. Within the utility boiler sector, coal is the largest energy source, representing 59% of utility fuel consumption. All three coals (anthracite, bituminous, and lignite) are used in utility boilers, but bituminous is the primary fuel (97%). Within bituminous coal-fired utility boilers, pulverized dry bottom units represent 72% of all fuel consumption, followed in order of decreasing fuel consumption by pulverized wet bottom units, cyclones, and stokers. Overall, this source type consumes 42% of the fossil fuel used in utility boilers and 11% of the total quantity of fossil fuels used for the generation of power or heat in the United States.[1,2]

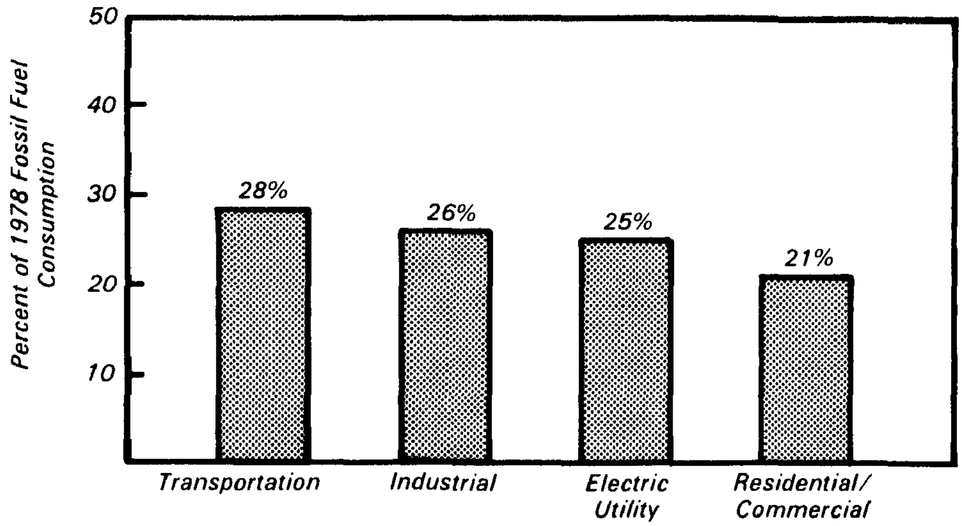

Figure 1. *Distribution of total fossil fuel consumption in 1978 by end use.*

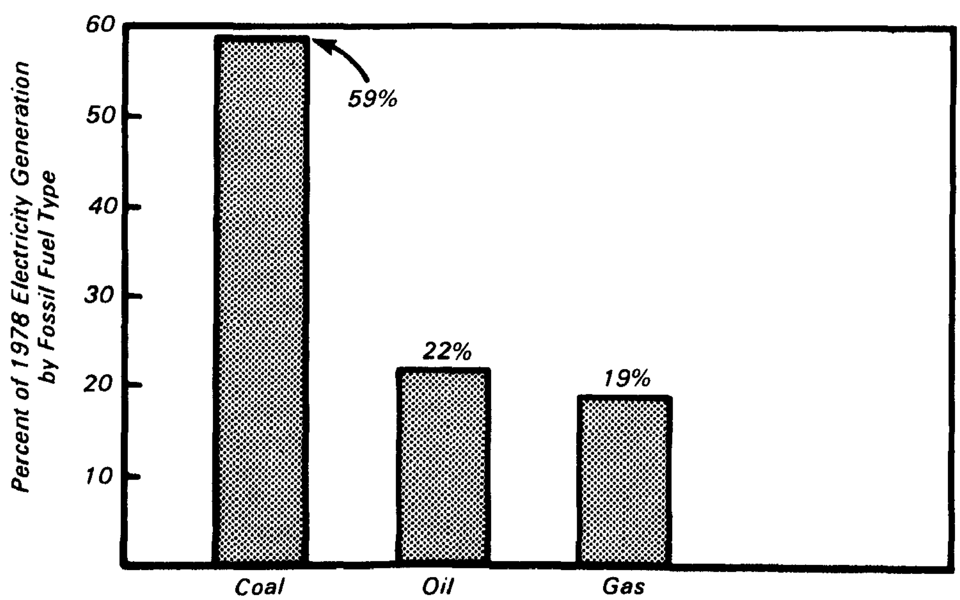

Figure 2. *Distribution of fossil fuels used to generate electricity in 1978.*

Summary

This document characterizes and assesses the potential impact of air emissions, wastewater effluents, and solid residues released to the environment by dry bottom utility boilers firing pulverized bituminous coal. This source is defined as all boilers (steam generators) that meet each of the following criteria:

- The primary fuel is pulverized bituminous coal.
- The operating temperature of the furnace is kept below the ash fusion temperature so that ash remaining in the furnace can be removed as a dry powder (dry bottom).
- The boiler is owned and operated by the utility sector to produce steam for electricity generation.

In 1978, this source category consumed an estimated 3.2×10^8 metric tons[a] of bituminous coal and represented 59% of the total U.S. steam electric generating capacity and 72% of utility coal combustion. States containing ≥5% of the boiler population or fuel consumption are listed in Table 1. Capacities of the individual boilers considered in this assessment range from <10 GJ/hr to 7,400 GJ/hr and average 300 GJ/hr.

Over 99% of the air emissions result from coal combustion in the furnace and are emitted from the boiler stack. Other emissions arise from coal storage and handling, cooling towers when used, and ash handling and disposal. Major emissions are the criteria pollutants: particulate matter, sulfur oxides (SO_x), nitrogen oxides (NO_x), hydrocarbons, and carbon monoxide (CO). Polycyclic

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[1] Annual Report to Congress 1978, Volume II: Data. DOE/EIA0173/2, U.S. Department of Energy, Energy Information Administration, Washington, D.C., 1978. 202 pp.

[2] Surprenant, N., R. Hall, S. Slater, T. Susa, M. Sussman, and C. Young. Preliminary Environmental Assessment of Conventional Stationary Combustion Systems; Volume II, Final Report. EPA-600/2-76-046b (PB 252 175), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 1976. 557 pp.

[a] 1 metric ton = 10^6 grams.

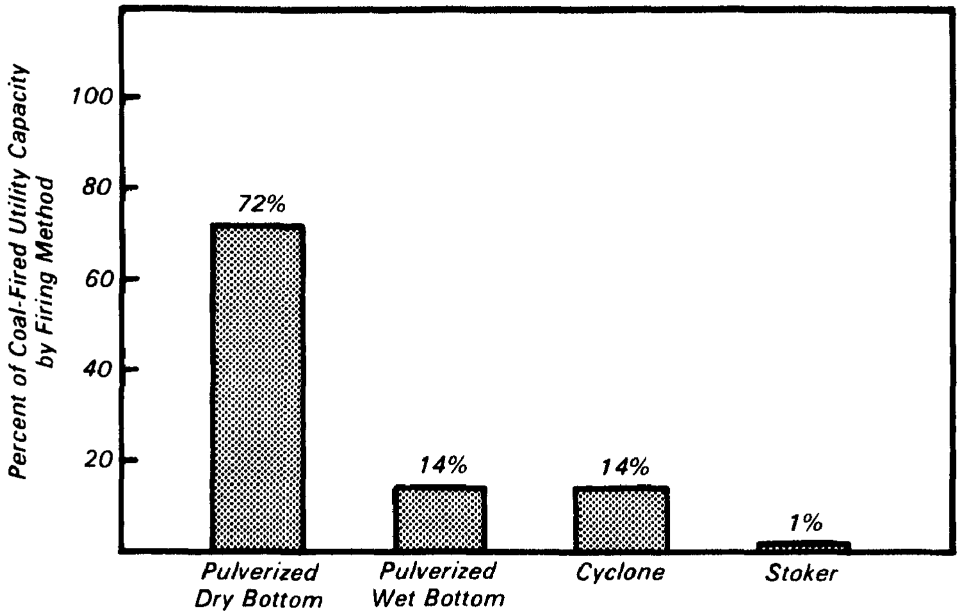

Figure 3. *Distribution of coal-fired electric utility capacity according to coal firing method, 1974.*

organic materials (POM) are among the hydrocarbon species emitted. In addition, trace elements are emitted as part of the particulate matter or in the vapor phase. The percent contribution of this source to the total state and national emission burdens of criteria pollutants are shown in Table 2. On both a state and national level, this source type is a major contributor to the emission burdens for SO_x, NO_x, and particulate matter.

Particulate emissions are controlled on approximately 86% of the sources according to the National Emissions Data System (NEDS) file for this source type. Particulate controls applied to these boilers include centrifugal collectors (23% of controls), electrostatic precipitators (58%), fabric filters (<1%), wet scrubbers (2%), and dual controls (17%). Of the dual control systems, 77% are centrifugal collector-electrostatic precipitator combinations, 18% are dual electrostatic precipitators, 4% are wet scrubber-electrostatic precipitator combinations, and 1% are centrifugal collector-wet scrubber combinations.

In order to evaluate the potential environmental effect of air emissions from an average source in this category, an ambient source severity, S_a, was defined as the ratio of the time-averaged maximum ground level concentration ($\bar{X}_{max}$) to an appropriate ambient environmental goal (F). The values of $\bar{X}_{max}$ were calculated from accepted plume dispersion equations and controlled emissions factors. The environmental goal is equal to the primary ambient air quality standard in the case of criteria pollutants (particulate matter, SO_x, NO_x, CO, and hydrocarbons) and to a reduced threshold limit value (TLV®), F = TLV × 8/24 × 1/100, for other pollutants. The factor 8/24 corrects for a 24-hr exposure while 1/100 is a safety factor.

Controlled emission factors and ambient source severities were calculated for an average size unit in this category. The average boiler was determined to fire coal having an ash content of 12.6% and a sulfur content of 2.08% at a rate of 11 kg/s. Flue gases are discharged into the atmosphere from a stack 92.6 m high with a plume rise of 59 m. Ambient severities from this average source are given in Table 3 and show that the highest values are for SO_x (0.93) and NO_x (0.97).

Another measure of potental environmental impact is the population which may be affected by emissions from an average source. The affected population is defined as the number of persons living in the area around an average size boiler where $\bar{X}$ (time-averaged ground level concentration) divided by F is greater than 1.0 or greater than 0.05. A $\bar{X}$/F value of 1.0 indicates exposure to a concentration of a pollutant greater than the environmental goal; the value of 0.05 allows for inherent uncertainties in measurement techniques, dispersion modeling, and health effects data. Plume dispersion equations are used to find this area, which is then multiplied by an average population density to determine the affected population. The average population around a utility boiler in this category is estimated to be 470 persons/km². The populations affected by emissions having $\bar{X}$/F greater than 0.05 are also shown in Table 3.

Water usage in utility boiler operations is highly variable. Waste streams common to most boilers in this category are boiler blowdown, wastes from feedwater treatment, and equipment cleaning wastes. Other waste streams which may or may not be present, depending on the boiler size, location, and application, are once-through cooling water for steam condensation and equipment cooling, recirculating cooling water blowdown, water from ash ponds, runoff from coal

Table 1. *States Containing ≥5% of the Total Number of Boilers or Fuel Consumption*

State	Percentage of boilers	Percentage of fuel consumption
Ohio	12.2	14.1
Pennsylvania	12.1	11.1
Michigan	8.6	7.2
Illinois	7.5	5.2
Indiana	5.9	6.5
Kentucky	5.2	6.0
New York	5.5	1.6
North Carolina	4.9	5.9
Tennessee	3.5	6.1
West Virginia	3.4	7.8
Total	68.8	71.5

Table 2. *Percent Contribution of Emissions from Dry Bottom Utility Boilers Firing Pulverized Bituminous Coal to Total State and National Emissions of Criteria Pollutants from Stationary Sources*

	Percent of total emissions burden				
State	Particulate matter	SO_x	NO_x	Hydrocarbons	CO
Alabama	30.3	60.8	60.3	2.1	0.4
Alaska	11.0	0.9	4.5	0.1	0.6
Arizona	5.4	2.6	5.6	0.1	0.1
Colorado	1.8	30.9	31.8	0.8	0.2
Delaware	2.3	26.8	16.7	0.2	0.4
Florida	3.8	35.6	14.3	0.3	0.1
Georgia	14.2	69.4	36.8	0.8	1.0
Illinois	14.7	49.5	20.7	0.3	0.1
Indiana	8.3	54.0	32.3	0.8	<0.1
Iowa	3.8	45.7	.16.6	0.7	3.4
Kansas	0.6	23.5	4.7	<0.1	0.3
Kentucky	25.2	74.8	50.3	1.5	0.7
Maryland	8.6	30.6	19.9	0.4	<0.1
Massachusetts	3.0	3.9	2.0	<0.1	0.5
Michigan	14.1	63.7	34.8	0.9	0.2
Minnesota	3.4	25.5	17.3	0.3	0.1
Mississippi	2.3	44.8	12.3	0.1	0.3
Missouri	0.6	23.3	12.4	0.2	1.0
Montana	0.2	11.7	10.6	0.1	0.2
Nebraska	1.8	27.3	14.5	0.2	1.2
Nevada	0.6	1.1	13.2	0.7	2.1
New Jersey	3.1	11.8	4.8	<0.1	0.6
New Mexico	21.5	38.9	42.0	0.5	8.4
New York	2.3	17.2	16.7	0.3	0.1
North Carolina	19.0	50.6	43.0	1.1	3.0
Ohio	30.9	70.3	40.6	1.0	0.1
Oklahoma	<0.1	<0.1	<0.1	<0.1	<0.1
Pennsylvania	12.3	50.6	37.3	0.7	0.1
South Carolina	6.5	12.2	48.8	0.1	0.1
Tennessee	37.0	73.1	45.4	1.6	4.5
Texas	0.4	3.5	3.1	<0.1	0.1
Utah	7.5	23.5	35.2	0.7	0.1
Virginia	25.5	16.4	19.8	0.3	1.0
Washington	0.1	3.0	25.2	0.3	0.6
West Virginia	17.4	58.1	56.6	2.4	0.5
Wisconsin	18.5	47.6	28.8	0.5	2.9
Wyoming	23.3	31.5	47.2	1.0	11.1
United States	9.3	44.5	25.6	0.4	0.2

storage piles, and effluent from SO_2 removal systems.

The potential impact of wastewater discharges was determined in a manner analogous to that used for air emissions. Effluent source severity, S_e, was defined as the ratio of the dispersed concentration of a pollutant in the receiving water to an effluent environmental goal. Water quality criterion values were used for environmental goals if available. If not, then 0.1 [LC_{50} (96-hr)] was used, for the aquatic species most sensitive to the pollutant of concern. An average receiving body for this source was determined to have a flow rate of 1.29×10^8 m^3/d. Effluent severities were found to be less than 1.0 for all pollutants from all discharge streams, and in almost all cases were below 0.01.

Solid wastes generated at coal-fired power plants consist of coal ash, SO_x scrubber sludge, and water treatment sludges. Of these, coal ash is the primary waste (>99%), although SO_x scrubber sludges will become a major waste as more stringent SO_2 regulations are implemented. The environmental impact of solid wastes from this source type is dependent on the disposal method used and the characteristics of the disposal site, which are variable.

Coal consumption by boilers covered in this assessment is expected to increase because of the growing demand for energy and the shortage of alternate fuel supplies (i.e., natural gas and oil). Total utility coal consumption is forecast to increase from 4.30×10^8 metric tons in 1978 to over 7.25×10^8 metric tons in 1985 and to over 1.36×10^9 metric tons by the year 2000.

Conclusions

Since the technological developments of the 1920's which made the use of pulverized coal practical, boilers firing pulverized coal have become the largest source of coal-derived electrical energy. By the mid-1970's, pulverized coal boilers (wet and dry bottom) accounted for 86% of all coal-fired boiler capacity. This percentage is expected to grow still higher because new power plants almost exclusively use pulverized coal firing.

Coal consumption by the utility sector has increased steadily for many decades, even though the proportion of electricity generated from coal has declined. Figure 4 shows the increase in utility coal consumption from 1950 to 1978. Over this same period, the percentage of electrical energy produced from coal dropped from 66% to 59% of the total electrical energy produced by fossil fuels.

A renewed interest in the use of coal resulted from the oil producing and exporting countries' (OPEC's) oil embargo of late 1973 which sharply increased oil prices, the recent natural gas shortages, and the inception of government policies directed towards making the United States self-sufficient in energy. President Carter's energy initiative of July 15, 1979, formalized the government's determination to reduce U.S. dependence on foreign oil. This initiative places a heavy emphasis on development of the nation's coal resources and the conversion of oil-fired power plants to coal firing. Coal is an obvious choice as a substitute for oil because coal reserves constitute the largest proven reserves of fossil fuel within the United States.

It is difficult to predict the actual growth of coal-fired generating capacity because of the many opposing factors acting to limit or enhance growth. Projections by the Electric Power

Research Institute (EPRI) call for an increase in utility coal consumption from 430 million metric tons in 1978 to over 725 million metric tons in 1985 and over 1.36 billion metric tons by the year 2000. Some of the major factors that will determine the actual growth rate are summarized as follows.

Factors Acting to Enhance Growth

- Decreasing supplies and rising costs of oil and natural gas
- Problems that are slowing down the expansion of nuclear power plant capacity
- Government restrictions on the import of foreign oil
- Government incentives or directives toward the use of coal

Factors Acting to Limit Growth

- Environmental regulations on the mining and combustion of coal
- Environmental standards restricting emissions of particulate matter, SO_x, NO_x, CO, hydrocarbons, and POM's
- Cost of required pollution control equipment
- Problem of disposal of wastes from pollution control systems
- Lack of adequate water suplies in the western United States
- Limitations in present railroad capacity for transporting coal
- Public opposition to siting of new power plants
- Increased substitution of solar heat for electric, residential, and commercial heat
- Increased conservation of electric energy use through wider application of computerized load management systems (which have short payoff times with high energy rates), and through other conservation schemes
- The impact of rate structure reform with an emphasis on long run marginal cost based rates

Pollutant emissions from coal-fired power plants are not predicted to increase as rapidly as the coal consumption rate because of increasingly stringent pollution control legislation.

Table 3. *Controlled Emission Factors, Source Severities, and Affected Populations for the Average Dry Bottom Utility Boiler Firing Pulverized Bituminous Coal*

Emission species	Controlled emission factor, g/kg of coal	Ambient source severity	Affected population for $S_a > 0.05$, persons
Particulate matter	$0.21A^a$	9.0×10^{-2}	19,000
NO_x	10^b	9.7×10^{-1}	300,000
SO_x	$19S^{b,c}$	9.3×10^{-1}	320,000
CO	0.5	1.9×10^{-4}	
Hydrocarbons	0.1	7.8×10^{-3}	0
POM (total)	1.6×10^{-5}	2.2×10^{-4}	0
POM (carcinogenic)	4.0×10^{-6}	1.0×10^{-2}	0
Elements:			
Aluminum	1.8×10^{-1}	4.9×10^{-2}	0
Antimony	1.2×10^{-3}	6.3×10^{-3}	0
Arsenic	2.6×10^{-2}	1.4×10^{-1}	36,000
Barium	1.0×10^{-3}	5.2×10^{-3}	0
Beryllium	2.1×10^{-5}	2.8×10^{-2}	0
Bismuth	$<1.0 \times 10^{-6}$	$<2.6 \times 10^{-7}$	0
Boron	2.9×10^{-2}	7.5×10^{-3}	0
Bromine	1.1×10^{-2}	4.1×10^{-2}	0
Cadmium	6.8×10^{-4}	3.6×10^{-2}	0
Calcium	1.3×10^{-2}	6.7×10^{-3}	0
Cerium	1.4×10^{-4}	3.7×10^{-5}	0
Cesium	2.5×10^{-4}	3.3×10^{-4}	0
Chlorine	7.3×10^{-1}	2.8×10^{-1}	82,000
Chromium	2.0×10^{-3}	5.2×10^{-2}	5,500
Cobalt	6.8×10^{-5}	1.8×10^{-3}	0
Copper	2.2×10^{-2}	6.0×10^{-2}	7,700
Dysprosium	1.4×10^{-5}	3.7×10^{-6}	0
Erbium	2.6×10^{-6}	6.7×10^{-7}	0
Europium	5.9×10^{-6}	1.6×10^{-6}	0
Fluorine	7.8×10^{-2}	1.0×10^{-1}	24,000
Gadolinium	1.0×10^{-5}	2.6×10^{-6}	0
Gallium	6.5×10^{-3}	1.7×10^{-3}	0
Germanium	$<4.8 \times 10^{-3}$	$<1.3 \times 10^{-3}$	0
Gold	$<1.0 \times 10^{-6}$	$<2.6 \times 10^{-7}$	0
Hafnium	1.2×10^{-5}	6.3×10^{-5}	0
Holmium	2.1×10^{-6}	5.6×10^{-6}	0
Iodine	1.1×10^{-3}	2.9×10^{-3}	0
Iridium	$<2.0 \times 10^{-6}$	$<5.2 \times 10^{-7}$	0
Iron	1.9×10^{-1}	1.0×10^{-1}	23,000
Lanthanum	9.3×10^{-5}	2.5×10^{-6}	0
Lead	1.5×10^{-2}	2.6×10^{-1}	81,000
Lithium	2.7×10^{-4}	7.1×10^{-5}	0
Lutetium	1.2×10^{-6}	3.2×10^{-7}	0
Magnesium	6.9×10^{-3}	1.8×10^{-3}	0
Manganese	5.9×10^{-3}	3.1×10^{-3}	0
Mercury	2.4×10^{-4}	1.3×10^{-2}	0
Molybdenum	3.1×10^{-3}	1.6×10^{-2}	0
Neodymium	1.2×10^{-4}	3.2×10^{-5}	0
Nickel	1.5×10^{-3}	4.1×10^{-2}	
Niobium	5.4×10^{-5}	1.4×10^{-6}	0
Osmium	$<2.0 \times 10^{-4}$	$<2.6 \times 10^{-1}$	78,000
Palladium	$<1.0 \times 10^{-6}$	$<2.6 \times 10^{-7}$	0
Phosphorus	9.2×10^{-2}	2.4×10^{-1}	70,000
Platinum	$<3.0 \times 10^{-6}$	$<4.1 \times 10^{-3}$	0
Potassium	2.3×10^{-2}	3.0×10^{-2}	0
Praeseodymium	2.1×10^{-5}	5.6×10^{-6}	0
Rhenium	$<2.0 \times 10^{-4}$	$<5.2 \times 10^{-5}$	0

Table 3. *(cont'd)*

Emission species	*Controlled emission factor, g/kg of coal*	*Ambient source severity*	*Affected population for $S_a > 0.05$, persons*
Rhodium	$<1.0 \times 10^{-6}$	$<2.6 \times 10^{-5}$	0
Rubidium	3.7×10^{-4}	9.7×10^{-5}	0
Ruthenium	$<1.0 \times 10^{-6}$	$<2.6 \times 10^{-7}$	0
Samarium	1.9×10^{-5}	4.9×10^{-6}	0
Scandium	5.1×10^{-5}	1.3×10^{-5}	0
Seleniun	4.5×10^{-3}	6.0×10^{-2}	
Silicon	2.7×10^{-1}	7.1×10^{-2}	8,600
Silver	2.5×10^{-5}	6.7×10^{-3}	13,000
Sodium	3.3×10^{-3}	4.1×10^{-3}	0
Strontium	1.0×10^{-3}	2.6×10^{-4}	0
Tantalum	9.5×10^{-6}	4.9×10^{-6}	0
Tellurium	3.4×10^{-4}	9.0×10^{-3}	0
Terbium	3.2×10^{-6}	8.6×10^{-7}	0
Thallium	1.0×10^{-4}	2.6×10^{-3}	0
Thorium	4.8×10^{-5}	1.3×10^{-5}	0
Thulium	$<1.0 \times 10^{-6}$	$<2.6 \times 10^{-7}$	0
Tin	2.4×10^{-5}	6.3×10^{-6}	0
Titanium	8.1×10^{-3}	2.1×10^{-3}	0
Tungsten	2.8×10^{-4}	7.5×10^{-4}	0
Uranium	1.4×10^{-4}	1.8×10^{-3}	0
Vanadium	2.0×10^{-3}	1.0×10^{-2}	0
Ytterbium	9.8×10^{-6}	2.6×10^{-6}	0
Yttrium	1.1×10^{-4}	2.9×10^{-4}	0
Zinc	1.8×10^{-2}	9.3×10^{-3}	0
Zirconium	5.0×10^{-4}	2.6×10^{-4}	0

[a] *Percent ash content of coal.*

[b] *Uncontrolled.*

[c] *Percent sulfur content of coal.*

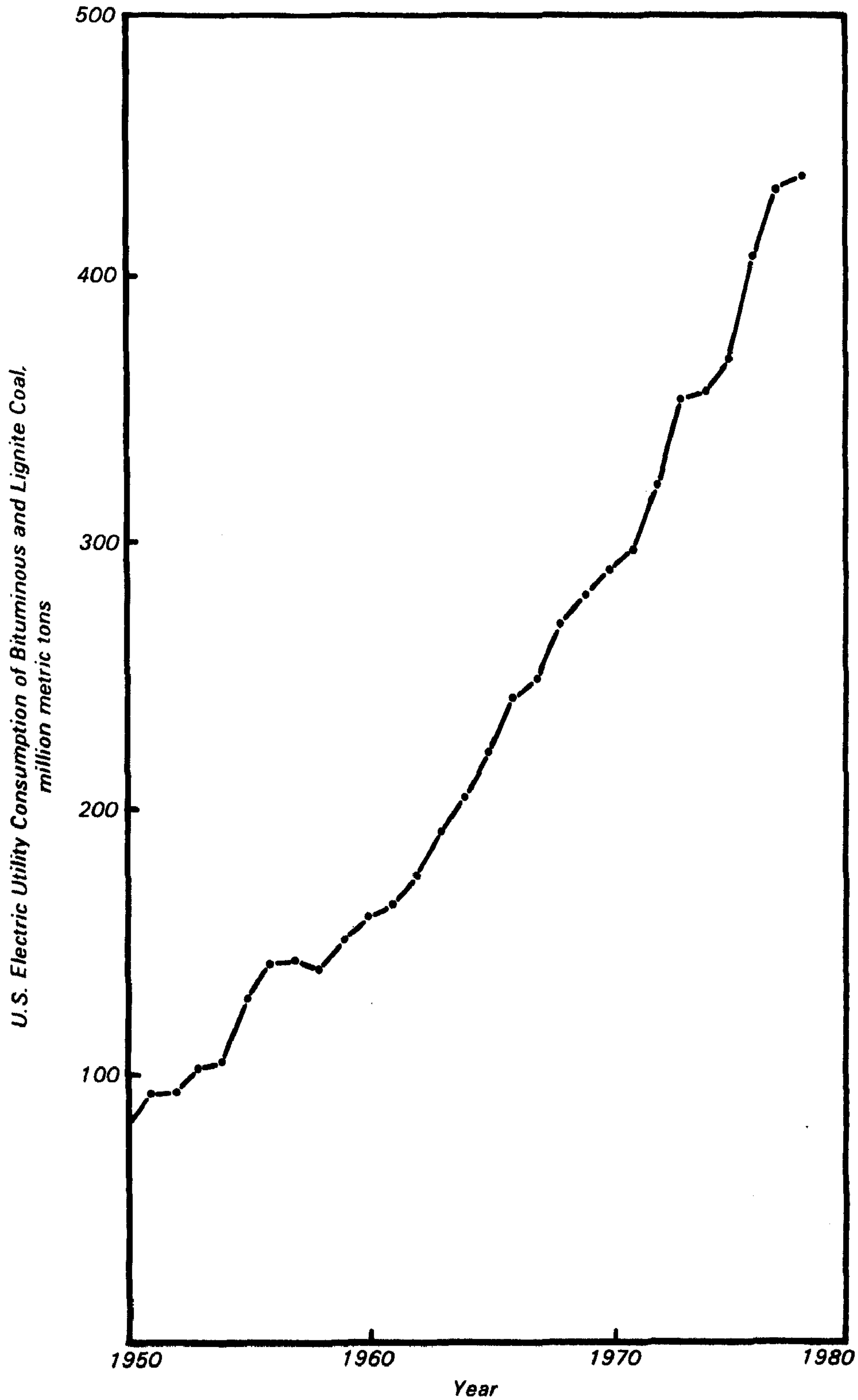

Figure 4. *Consumption of bituminous and lignite coals by electric utilities, 1950-1978*

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