Emission Factor Documentation for AP-42
Section 11.6

Portland Cement Manufacturing

Final Report

For U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Inventory Branch

EPA Contract 68-D2-0159
Work Assignment No. I-01

MRI Project No. 4601-01

May 18, 1994

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For U. S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Emission Inventory Branch
Research Triangle Park, NC 27711

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PREFACE

This report was prepared by Midwest Research Institute (MRI) for the Office of Air Quality Planning and Standards (OAQPS), U. S. Environmental Protection Agency (EPA), under Contract No. 68-D2-0159, Work Assignment No. I-01. Mr. Ron Myers was the requester of the work. The report was prepared by Richard Marinshaw and Dennis Wallace.

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1.0 INTRODUCTION

The document "Compilation of Air Pollutant Emissions Factors" (AP-42) has been published by the U. S. Environmental Protection Agency (EPA) since 1972. Supplements to AP-42 have been routinely published to add new emission source categories and to update existing emission factors. AP-42 is routinely updated by EPA to respond to new emission factor needs of EPA, State and local air pollution control programs, and industry.

An emission factor relates the quantity (weight) of pollutants emitted to a unit of activity of the source. The uses for the emission factors reported in AP-42 include:

1. Estimates of areawide emissions;
2. Estimates of emissions for a specific facility; and
3. Evaluation of emissions relative to ambient air quality.

The purpose of this report is to provide background information from test reports and other information to support the revision of AP-42 Section 11.6, Portland Cement Manufacturing.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a description of the portland cement industry. It includes a characterization of the industry, an overview of the different process types, a description of emissions, and a description of the technology used to control emissions resulting from portland cement production. Section 3 is a review of emission data collection and analysis procedures. It describes the literature search, the screening of emission data reports, and the quality rating system for both emission data and emission factors. Section 4 details revisions to the previous AP-42 section narrative and pollutant emission factor development. It includes the review of specific data sets and the results of data analysis. Section 5 presents AP-42 Section 11.6.

2.0 INDUSTRY DESCRIPTION[1,2]

Portland cement is a fine powder, gray or white in color, that consists of a mixture of hydraulic cement materials comprising primarily calcium silicates. More than 30 raw materials are known to be used in the manufacture of portland cement, and these materials can be divided into four distinct categories: calcareous, siliceous, argillaceous, and ferrifrous. These materials are chemically combined via pyroprocessing and subjected to subsequent mechanical processing operations to form gray and white portland cement. Gray portland cement is used for structural applications and is the more common type of cement produced. White portland cement has lower iron and manganese contents than gray portland cement and is used primarily for decorative purposes. Portland cement manufacturing plants are included under Standard Industrial Code (SIC) Code 3241, hydraulic cement manufacturing, which also includes natural, masonry, and pozzolanic cement. The six-digit Source Classification Code (SCC) for portland cement plants with wet process kilns is 3-05-006, and the six-digit SCC for plants with dry process kilns is 3-05-007.

2.1 CHARACTERIZATION OF THE INDUSTRY[1-4]

As of December 1990, there were 112 operating portland cement plants in the United States, with 109 of these plants producing gray cement and the other 3 producing white cement. These 112 plants operated 213 kilns with a total annual clinker capacity of 73.7×10^6 Mg (81×10^6 tons). The kiln population included 80 wet process kilns and 133 dry process kilns. Both the number of facilities and the industry capacity declined in 1990; two plants with a total annual clinker capacity of 492×10^3 megagrams (Mg) (541×10^3 tons) were retired during the year. This decline continues a trend in the industry, which has shown a reduction in clinker capacity in 8 of the last 11 years. The other major trend in the industry is the increased use of waste fuels. In 1989, 33 plants in the United States and Canada reported using waste fuels; the number increased to 55 plants in 1990.

The portland cement manufacturing industry is dispersed geographically throughout the United States, with 36 States having at least one plant. Table 2-1 shows the total number of operating plants and kilns and the total clinker capacity for each State and EPA Region.

2.2 PROCESS DESCRIPTION[1-6]

Portland cement, which consists of a mixture of the hydraulic cement minerals, calcium silicates, aluminates and aluminoferrites, and calcium sulfates, accounts for 95 percent of the hydraulic cement production in the United States. The balance of domestic cement production comprises primarily masonry cement. Both of these materials are produced in portland cement manufacturing plants. A diagram of the process, which encompasses production of both portland and masonry cement, is shown in Figure 2-1. As shown in the figure, the process can be divided into the following primary components: raw materials acquisition and handling, kiln feed preparation, pyroprocessing, and finished cement grinding. Each of these process components is described briefly below. The focus of the discussion is on pyroprocessing operations, which constitute the core of a portland cement plant.

The initial production step in portland cement manufacturing is raw materials acquisition. More than 30 raw materials are known to be used to manufacture portland cement. Calcium, the element of highest concentration in portland cement, is obtained from a variety of calcareous raw materials, including limestone, chalk, marl, sea shells, aragonite, and an impure limestone known as "natural cement rock".

TABLE 2-1. SUMMARY OF PORTLAND CEMENT PLANT CAPACITY INFORMATION[a]

Location	Number of plants, kilns	Capacity, 10^3 Mg/yr (10^3 tons/yr)
Region I	1 (1)	414 (455)
Connecticut	0	0 (0)
Maine	1 (1)	414 (455)
Massachusetts	0	0 (0)
New Hampshire	0	0 (0)
Rhode Island	0	0 (0)
Vermont	0	0 (0)
Region II	4 (5)	2,815 (3,097)
New Jersey	0	0 (0)
New York	4 (5)	2,815 (3,097)
Puerto Rico	NA	NA
Virgin Islands	NA	NA
Region III	16 (39)	9,492 (10,442)
Delaware	0	0 (0)
District of Columbia	0	0 (0)
Maryland	3 (7)	1,691 (1,860)
Pennsylvania	11 (24)	6,039 (6,643)
Virginia	1 (5)	1,015 (1,117)
West Virginia	1 (3)	747 (822)
Region IV		12,599 (13,858)
Alabama	5 (6)	3,873 (4,260)
Florida	6 (8)	3,057 (3,363)
Georgia	2 (4)	1,253 (1,378)
Kentucky	1 (1)	658 (724)
Mississippi	1 (1)	458 (504)
North Carolina	0	0 (0)
South Carolina	3 (7)	2,345 (2,579)
Tennessee	2 (3)	955 (1,050)
Region V	17 (30)	10,924 (12,016)
Illinois	4 (8)	2,350 (2,585)
Indiana	4 (8)	2,573 (2,830)
Michigan	5 (9)	4,453 (4,898)
Minnesota	0	0 (0)
Ohio	4 (5)	1,548 (1,703)
Wisconsin	0	0 (0)
Region VI	18 (34)	11,165 (12,282)
Arkansas	2 (5)	1,195 (1,314)
Louisiana	0	0 (0)
New Mexico	1 (2)	449 (494)
Oklahoma	3 (7)	1,715 (1,887)
Texas	12 (20)	7,806 (8,587)

TABLE 2-1. (continued)

Location	Number of plants, kilns	Capacity, 10^3 Mg/yr (10^3 tons/yr)
Region VII	14 (27)	9,393 (10,332)
Iowa	4 (7)	2,551 (2,806)
Kansas	4 (11)	1,716 (1,888)
Missouri	5 (7)	4,252 (4,677)
Nebraska	1 (2)	874 (961)
Region VIII	9 (14)	4,137 (4,551)
Colorado	3 (5)	1,640 (1,804)
Montana	2 (2)	538 (592)
North Dakota	0	0 (0)
South Dakota	1 (3)	696 (766)
Utah	2 (3)	844 (928)
Wyoming	1 (1)	419 (461)
Region IX	16 (30)	11,672 (12,840)
Arizona	2 (7)	1,609 (1,770)
California	12 (20)	9,447 (10,392)
Hawaii	1 (1)	239 (263)
Nevada	1 (2)	377 (415)
American Samoa	NA	
Virgin Islands	NA	
Region X	4 (4)	1,057 (1,163)
Alaska	1 (0)[b]	0 (0)
Idaho	1 (2)	191 (210)
Oregon	1 (1)	436 (480)
Washington	1 (1)	430 (473)

NA = Data not available.
[a]Reference 2.
[b]Grinding plant only.

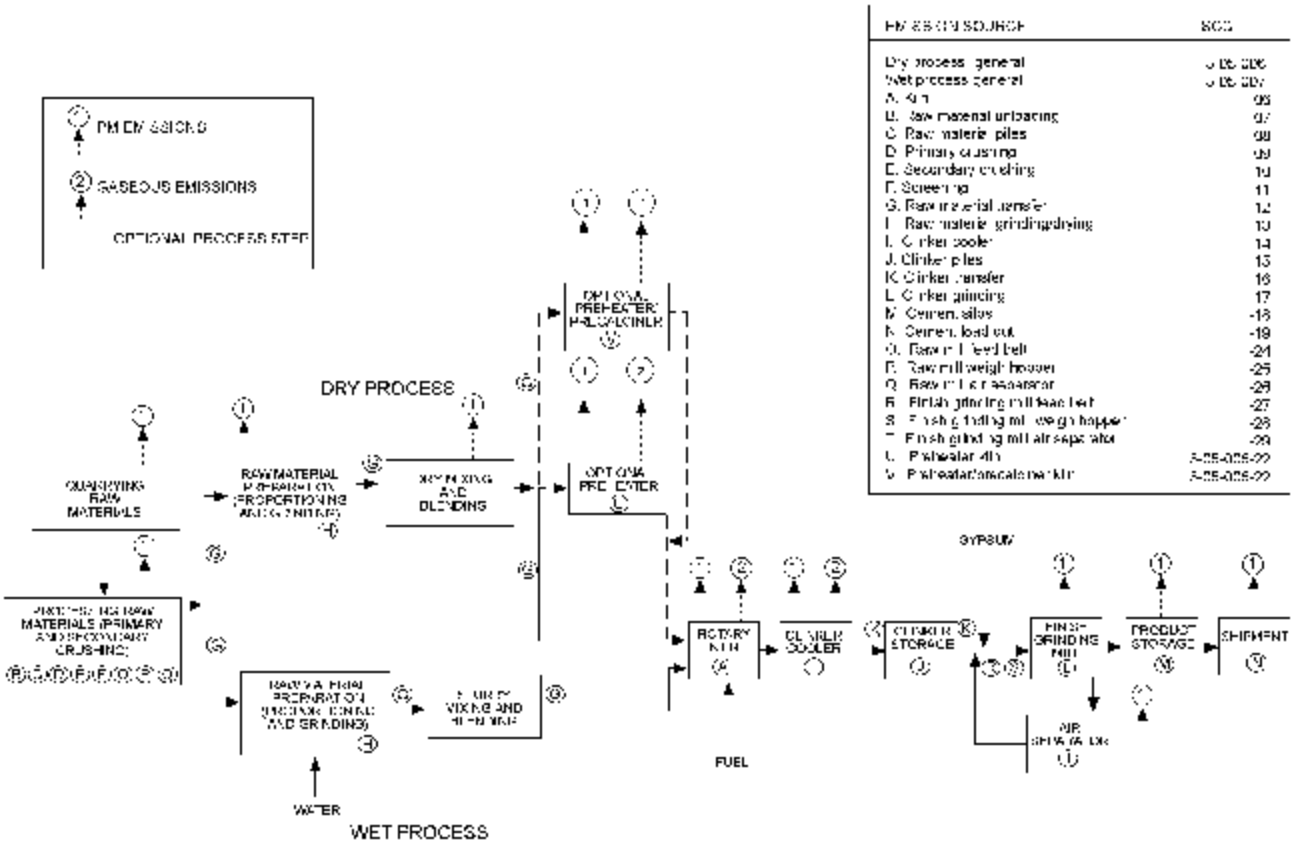

Figure 2-1. Process Flow Diagram for Portland Cement Manucturing.
(SCC = Source Classification Code)

Typically, these raw materials are obtained from open-face quarries, but underground mines or dredging operations are also used. Raw materials vary from facility to facility. The materials found in some quarries that supply raw materials for portland cement have a high degree of calcinated limestone, whereas the material from other limestone quarries must be blended with "cleaner" limestone to produce an acceptable product. In addition, pockets of pyrite, which significantly increase emissions of sulfur dioxide (SO_2), can be found in deposits of limestone, clays, and shales used as raw materials for portland cement. Because a large fraction (approximately one third) of the mass of this primary material is converted to carbon dioxide (CO_2) in the kiln, portland cement plants are located in close proximity to a raw material source whenever possible. Other metallic elements included in the raw feed mix are silicon, aluminum, and iron. These materials are obtained from ores and minerals such as sand, shale, clay, and iron ore. Again, these materials are most commonly extracted via open-pit quarries or mines, but they may be dredged or excavated from underwater deposits.

Either gypsum or natural anhydrite, both of which are forms of calcium sulfate, is introduced to the process during the finish grinding operations described below. These materials are also excavated from quarries or mines. However, they are generally purchased from an external source, rather than obtained directly from a captive operation by the cement plant. In addition, the portland cement manufacturing industry is relying increasingly on replacing virgin materials as described above with waste materials or byproducts from other manufacturing operations, to the extent that such replacement can be implemented without adversely affecting plant operations or product quality. Materials that have been used include fly ash, mill scale, and metal smelting slags.

The second step in portland cement manufacture is preparing the raw mix or kiln feed for the pyroprocessing operation. Raw material preparation includes a variety of blending and sizing operations that are designed to provide a feed with appropriate chemical and physical properties. The raw material processing operations differ somewhat for wet and dry processes, as described in the paragraphs below.

Cement raw materials are received with an initial moisture content varying from 1 to more than 50 percent. If the facility uses dry process kilns, this moisture is usually reduced to less than 1 percent before or during grinding. Drying alone can be accomplished in impact dryers, drum dryers, paddle-equipped rapid dryers, air separators, or autogenous mills. However, drying can also be accomplished during grinding in ball-and-tube mills or roller mills. While thermal energy for drying can be supplied by exhaust gases from separate, direct-fired coal, oil, or gas burners, the most efficient and widely used source of heat for drying is the hot exit gases from the pyroprocessing system.

Materials transport associated with raw milling systems can be accomplished by a variety of mechanisms, including screw conveyors, belt conveyors, drag conveyors, bucket elevators, air slide conveyors, and pneumatic conveying systems. The dry raw mix is pneumatically blended and stored in specially constructed silos until it is fed to the pyroprocessing system.

In the wet process, water is added to the raw mill during the grinding of the raw materials in ball or tube mills, thereby producing a pumpable slip or slurry of approximately 65 percent solids. The slurry is agitated, blended, and stored in various kinds and sizes of cylindrical tanks or slurry basins until it is fed to the pyroprocessing system.

The heart of the portland cement manufacturing process is the pyroprocessing system. This system transforms the raw mix into clinkers, which are gray, glass-hard, spherically shaped nodules that

range from 0.32 to 5.1 centimeters (cm) (0.125 to 2.0 inches [in.]) in diameter. The chemical reactions and physical processes that constitute the transformation are quite complex, but they can be viewed conceptually as the following sequential events:

1. Evaporation of free water;

2. Evolution of combined water in the argillaceous components;

3. Calcination of the calcium carbonate ($CaCO_3$) to calcium oxide (CaO);

4. Reaction of CaO with silica to form dicalcium silicate;

5. Reaction of CaO with the aluminum and iron-bearing constituents to form the liquid phase;

6. Formation of the clinker nodules;

7. Evaporation of volatile constituents (e.g., sodium, potassium, chlorides, and sulfates); and

8. Reaction of excess CaO with dicalcium silicate to form tricalcium silicate.

This sequence of events may be conveniently divided into four stages, as a function of location and temperature of the materials in the rotary kiln.

1. Evaporation of uncombined water from raw materials as material temperature increases to 100EC (212EF);

2. Dehydration as the material temperature increases from 100EC to approximately 430EC (800EF) to form oxides of silicon, aluminum, and iron;

3. Calcination, during which carbon dioxide (CO_2) is evolved, between 900EC (1650EF) and 982EC (1800EF), to form CaO; and

4. Reaction of the oxides in the burning zone of the rotary kiln to form cement clinker at temperatures of approximately 1510EC (2750EF).

Rotary kilns are long, cylindrical, slightly inclined furnaces that are lined with refractory to protect the steel shell and retain heat within the kiln. The raw material mix enters the kiln at the elevated end, and the combustion fuels generally are introduced into the lower end of the kiln in a countercurrent manner. The materials are continuously and slowly moved to the lower end by rotation of the kiln. As they move down the kiln, the raw materials are changed to cementitious metal oxides by the direct heat exchange. The most commonly used kiln fuels are coal, natural gas, and occasionally oil. Many cement plants currently burn coal, but use of supplemental fuels such as waste solvents, scrap rubber, and petroleum coke has expanded in recent years.

Five different processes are used in the portland cement industry to accomplish the pyroprocessing step: the wet process, the dry process (long dry process), the semidry process, the dry process with a preheater, and the dry process with a preheater/precalciner. Each of these processes

accomplishes the physical/chemical steps defined above. However, the processes vary with respect to equipment design, method of operation, and fuel consumption. Generally, fuel consumption decreases in the order of the processes listed above. The paragraphs below briefly describe the process, starting with the wet process and then noting differences in the other processes.

In the wet process and long dry process, all of the pyroprocessing activity occurs in the rotary kiln. Depending on the process type, kilns have length-to-diameter ratios in the range of 15:1 to 40:1. While some wet process kilns may be as long as 210 m (700 ft), many wet process kilns and all dry process kilns are shorter. Wet process and long dry process pyroprocessing systems consist solely of the simple rotary kiln. Usually, a system of chains is provided at the feed end of the kiln in the drying or preheat zones to improve heat transfer from the hot gases to the solid materials. As the kiln rotates, the chains are raised and exposed to the hot gases. Further kiln rotation causes the hot chains to fall into the cooler materials at the bottom of the kiln, thereby transferring the heat to the load.

Dry process pyroprocessing systems have been improved in thermal efficiency and productive capacity through the addition of one or more cyclone-type preheater vessels in the gas stream after the rotary kiln. This system is called the preheater process. The vessels are arranged vertically, in series, and are supported by a structure known as the preheater tower. Hot exhaust gases from the rotary kiln pass countercurrently through the downward-moving raw materials in the preheater vessels. Compared with the simple rotary kiln, the heat transfer rate is significantly increased, the degree of heat utilization is more complete, and the process time is markedly reduced owing to the intimate contact of the solid particles with the hot gases. The improved heat transfer allows the length of the rotary kiln to be reduced. The hot gases from the preheater tower are often used as a source of heat for drying raw materials in the raw mill. Because the catch from the mechanical collectors, fabric filters, and/or electrostatic precipitators (ESP's) that follow the raw mill is returned to the process, these devices are considered to be production machines as well as pollution control devices.

Additional thermal efficiencies and productivity gains have been achieved by diverting some fuel to a calciner vessel at the base of the preheater tower. This system is called the preheater/precalciner process. While a substantial amount of fuel is used in the precalciner, at least 40 percent of the thermal energy is required in the rotary kiln. The amount of fuel that is introduced to the calciner is determined by the availability and source of the oxygen for combustion in the calciner. Calciner systems sometimes use lower-quality fuels (e.g., less-volatile matter) as a means of improving process economics.

Preheater and precalciner kiln systems often have a bypass system between the feed end of the rotary kiln and the preheater tower to remove the undesirable volatile constituents. Otherwise, the volatile constituents condense in the preheater tower and subsequently recirculate to the kiln. Buildup of these condensed materials can restrict process and gas flows. In a bypass system, a portion of the kiln exit gas stream is withdrawn and quickly cooled by air or water to condense the volatile constituents to fine particles. The solid particles, which are removed from the gas stream by fabric filters and ESP's, are then returned to the process.

The semidry process is a variation of the dry process. In the semidry process, the water is added to the dry raw mix in a pelletizer to form moist nodules or pellets. The pellets then are conveyed on a moving grate preheater before being fed to the rotary kiln. The pellets are dried and partially calcined on the moving grate through which hot kiln exhaust gases pass.

Regardless of the type of pyroprocess used, the last component of the pyroprocessing system is the clinker cooler. This process step recoups up to 30 percent of the heat input to the kiln system, locks in desirable product qualities by freezing mineralogy, and makes it possible to handle the cooled clinker with conventional conveying equipment. The more common types of clinker coolers are (1) reciprocating grate, (2) planetary, and (3) rotary. In these coolers, the clinker is cooled from about 1100EC to 93EC (2000EF to 200EF) by ambient air that passes through the clinker and into the rotary kiln for use as combustion air. However, in the reciprocating grate cooler, lower clinker discharge temperatures are achieved by passing an additional quantity of air through the clinker. Because this additional air cannot be utilized in the kiln for efficient combustion, it is vented to the atmosphere, used for drying coal or raw materials, or used as a combustion air source for the precalciner.

The final step in portland cement manufacturing involves a sequence of blending and grinding operations that transforms clinker to finished portland cement. Up to 5 percent gypsum or natural anhydrite is added to the clinker during grinding to control the cement setting time, and other specialty chemicals are added as needed to impart specific product properties. This finish milling is accomplished almost exclusively in ball or tube mills. Typically, finishing is conducted in a closed- circuit system with product sizing via air separation.

2.3 EMISSIONS[1,2,4-8]

Particulate matter (PM and PM-10), nitrogen oxides (NO_x), SO_2, carbon monoxide (CO), and CO_2 are the primary emissions in the manufacture of portland cement. Small quantities of volatile organic compounds (VOC), ammonia (NH_3), chlorine, and hydrogen chloride (HCl), also may be emitted. Emissions may also include residual materials from the fuel and raw materials or products of incomplete combustion that are considered to be hazardous. Because some facilities burn waste fuels, particularly spent solvents in the kiln and these systems also may emit small quantities of additional hazardous organic pollutants. Also, raw material feeds and fuels typically contain trace amounts of heavy metals that may be emitted as a particulate or a vapor.

Sources of PM at cement plants include (1) quarrying and crushing, (2) raw material storage, (3) grinding and blending (in the dry process only), (4) clinker production, (5) finish grinding, and (6) packaging and loading. The largest emission source of PM within cement plants is the pyroprocessing system that includes the kiln and clinker cooler exhaust stacks. Emissions from kilns are affected by several factors, including differences in convective patterns, material movement patterns, burner locations and insertion lengths, heat transfer mechanisms, and the type of clinker cooler that supplies secondary air to the kiln for combustion. In addition, operators can vary the degree of calcination that takes place within a preheater or precalciner. Often, dust from the kiln is collected and recycled into the kiln thereby producing clinker from the dust. However, if the alkali content of the raw materials is too high, some or all of the dust is discarded or leached before returning it to the kiln. In many instances, the maximum allowable cement alkali content of 0.6 percent (calculated as sodium oxide) restricts the amount of dust that can be recycled. Bypass systems sometimes have a separate exhaust stack. Additional sources of PM are raw material storage piles, conveyors, storage silos, and unloading facilities.

Oxides of nitrogen are generated during fuel combustion by oxidation of chemically bound nitrogen in the fuel and by thermal fixation of nitrogen in the combustion air. As flame temperature increases, the amount of thermally generated NO_x increases, and the amount of NO_x generated from fuel increases with the quantity of nitrogen in the fuel. In the cement manufacturing process, NO_x is

generated in the burning zone of the kiln and the burning zone of a precalcining vessel. Fuel use affects the quantity and type of NO_x generated. For example, natural gas combustion with a high flame temperature and low fuel nitrogen generates a larger quantity of NO_x than does oil or coal, which have higher fuel nitrogen but burn with lower flame temperatures. Types of fuels used vary across the industry. Historically, some combination of coal, oil, and natural gas was used, but over the last 15 years, most plants switched to coal, which generates less NO_x than does oil or gas. However, in recent years a number of plants have switched to systems that burn a combination of coal and waste fuel. The effect of waste fuel use on NO_x emissions is not clearly established.

Sulfur dioxide may be generated both from the sulfur compounds in the raw materials and from sulfur in the fuel. The sulfur content of both raw materials and fuels varies from plant to plant and with geographic location. However, the alkaline nature of the cement provides for direct absorption of SO_2 into the product, thereby mitigating the quantity of SO_2 emissions in the exhaust stream.

The CO_2 emissions from portland cement manufacturing are generated by two mechanisms. As with most high-temperature, energy-intensive industrial processes, combustion of fuels to generate process energy releases substantial quantities of CO_2. Substantial quantities of CO_2 also are generated through calcining of limestone or other calcareous material. This calcining process thermally decomposes $CaCO_3$ to CaO and CO_2. Typically, portland cement contains the equivalent of about 63.5 percent CaO. Consequently about 1.135 units of $CaCO_3$ are required to produce 1 unit of cement, and the amount of CO_2 released in the calcining process is about 500 kilograms (kg) per Mg of portland cement produced (1,000 pounds [lb] per ton of cement).

In addition to CO_2 emissions, fuel combustion at portland cement plants can emit a wide range of pollutants in smaller quantities. If the combustion reactions do not reach completion, CO and volatile organic pollutants, which are typically measured as total organic compounds (TOC), VOC, or condensible organic particulate, can be emitted. Incomplete combustion also can lead to emissions of specific hazardous organic air pollutants, although these pollutants are generally emitted at substantially lower levels than CO or TOC.

Emissions of metal compounds from portland cement kilns can be grouped into three general classes: volatile metals, including mercury (Hg) and thallium (Tl); semivolatile metals, including antimony (Sb), cadmium (Cd), lead (Pb), selenium (Se), zinc (Zn), potassium (K), and sodium (Na); and refractory or nonvolatile metals, including barium (Ba), chromium (Cr), arsenic (As), nickel (Ni), vanadium (V), manganese (Mn), copper (Cu), and silver (Ag). Although the partitioning of these metal groups is affected by kiln operating conditions, the refractory metals tend to concentrate in the clinker, while the volatile and semivolatile metals tend to be discharged via the primary exhaust stack and the by-pass stack, respectively.

2.4 CONTROL TECHNOLOGY[1-3]

Fugitive dust sources in the industry include quarrying and mining operations, vehicular traffic during mineral extraction and at the manufacturing site, raw materials storage piles, and clinker storage piles. The measures used to control emissions from these fugitive dust sources are comparable to those used throughout the mineral products industries. Vehicular traffic controls include paving and road wetting. Controls that are applied to other open dust sources include water sprays with and without surfactants, chemical dust suppressants, wind screens, and process modifications to reduce drop heights

or enclose storage operations. Additional information on these control measures can be found in Chapter 11 of AP-42.

Process fugitive emission sources include materials handling and transfer, raw milling operations in dry process facilities, and finish milling operations. Typically, emissions from these processes are captured by a ventilation system and collected in fabric filters. Some facilities use an air pollution control system comprising one or more mechanical collectors with a fabric filter in series. Because the dust from these units is returned to the process, they are considered to be process units as well as air pollution control devices. The industry uses shaker, reverse air, and pulse jet filters as well as some cartridge units, but most newer facilities use pulse jet filters. For process fugitive operations, the different systems are reported to achieve typical outlet PM loadings of 45 milligrams per cubic meter (mg/m^3) (0.02 grains per actual cubic foot [gr/acf]).

In the pyroprocessing units, PM emissions are controlled by fabric filters (reverse air, pulse jet, or pulse plenum) and ESP's. Typical control measures for the kiln exhaust are reverse air fabric filters with an air-to-cloth ratio of 0.41:1 meter per minute (m/min) (1.5:1 $acfm/ft^2$) and ESP's with a net SCA of 1,140 to 1,620 square meters per thousand m^3 ($m^2/1{,}000\ m^3$) (350 to 500 square feet per thousand ft^3 [$ft^2/1{,}000\ ft^3$]). These systems are reported to achieve outlet PM loadings of 45 mg/m^3 (0.02 gr/acf). Clinker cooler systems are controlled most frequently with pulse jet or pulse plenum fabric filters. A few gravel bed filters also have been used to control clinker cooler emissions. Typical outlet PM loadings are identical to those reported for kilns.

Cement kiln systems have highly alkaline internal environments that can absorb up to 95 percent of potential SO_2 emissions. However, in systems that have sulfide sulfur (pyrites) in the kiln feed, the sulfur absorption rate may be as low as 50 percent without unique design considerations or changes in raw materials. The cement kiln system itself has been determined to provide substantial SO_2 control. Fabric filters on cement kilns are also reported to absorb SO_2. Generally, substantial control is not achieved. An absorbing reagent (e.g., CaO) must be present in the filter cake for SO_2 capture to occur. Without the presence of water, which is undesirable in the operation of a fabric filter, $CaCO_3$ is not an absorbing reagent. It has been observed that as much as 50 percent of the SO_2 can be removed from the pyroprocessing system exhaust gases when this gas stream is used in a raw mill for heat recovery and drying. In this case, moisture and calcium carbonate are simultaneously present for sufficient time to accomplish the chemical reaction with SO_2.

REFERENCES FOR SECTION 2

1. W. L. Greer, *et al.*, "Portland Cement", *Air Pollution Engineering Manual*, A. J. Buonicore and W. T. Davis (eds.), Von Nostrand Reinhold, New York 1992.

2. Written communication from Walter Greer, Ash Grove Cement Company, Overland Park, Kansas, to R. Myers, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 30, 1993.

3. *U. S. and Canadian Portland Cement Industry Plant Information Summary, December 31, 1990*, Portland Cement Association, Washington, DC, August 1991.

4. "Chapter 11.6, Portland Cement Manufacturing, *Compilation of Air Pollutant Emission Factors, AP-42*, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1991.

5. Written communication from John Wheeler, Capitol Cement, San Antonio, Texas, to R. Myers, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 21, 1993.

6. Written communication from F. L. Streitman, ESSROC Materials, Incorporated, Nazareth, Pennsylvania, to R. Myers, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 29, 1993.

7. Written communication from Robert W. Crolius, Portland Cement Association, to Ron Myers, U. S. Environmental Protection Agency, Research Triangle Park, NC. March 11, 1992.

8. Dellinger, H.B., D.W. Pershing, and A.F. Sarofim. *Evaluation of the Origin, Emissions and Control of Organic and Metal Compounds from Cement Kilns Fired with Hazardous Wastes*. Science Advisory Board on Cement Kiln Recycling. June 1993.

3.0 GENERAL DATA REVIEW AND ANALYSIS

3.1 LITERATURE SEARCH AND SCREENING[1]

Data for this investigation were obtained from a number of sources within the Office of Air Quality Planning and Standards (OAQPS) and from outside organizations. The AP-42 Background Files located in the Emission Inventory Branch (EIB) were reviewed for information on the industry, processes, and emissions. The Crosswalk/Air Toxic Emission Factor Data Base Management System (XATEF) and VOC/PM Speciation Data Base Management System (SPECIATE) data bases were searched by SCC code to identify potential pollutants emitted and emission factors for those pollutants. A general search of the Air CHIEF CD-ROM also was conducted to supplement the information from these two data bases. Information on the industry, including number of plants, plant location, and annual production capacities was obtained from industry reports recently prepared by the Portland Cement Association (PCA).

A number of sources of information were investigated specifically for emission test reports and data. A search of the Test Method Storage and Retrieval (TSAR) data base was conducted to identify test reports for sources within the portland cement industry. Copies of these test reports were obtained from the files of the Emission Measurement Branch (EMB). The EPA library was searched for additional test reports. A list of plants that have been tested within the past 5 years was compiled from the AIRS data base. Using this information, State and Regional offices were contacted about the availability of test reports. However, the information obtained from these offices was limited. Publications lists from the Office of Research and Development (ORD) and Control Technology Center (CTC) were also searched for reports on emissions from the portland cement industry. In addition, the PCA was contacted for assistance in obtaining information about the industry and emissions, and information supplied by PCA for the 1989 AP-42 revision was received.

To screen out unusable test reports, documents, and information from which emission factors could not be developed, the following general criteria were used:

1. Emission data must be from a primary reference:
   a. Source testing must be from a referenced study that does not reiterate information from previous studies.
   b. The document must constitute the original source of test data. For example, a technical paper was not included if the original study was contained in the previous document. If the exact source of the data could not be determined, the document was eliminated.
2. The referenced study must contain test results based on more than one test run.
3. The report must contain sufficient data to evaluate the testing procedures and source operating conditions (e.g., one-page reports were generally rejected).

A final set of reference materials was compiled after a thorough review of the pertinent reports, documents, and information according to these criteria.

3.2 EMISSION DATA QUALITY RATING SYSTEM

As part of the analysis of the emission data, the quantity and quality of the information contained in the final set of reference documents were evaluated. The following data were excluded from consideration:

1. Test series averages reported in units that cannot be converted to the selected reporting units;

2. Test series representing incompatible test methods (i.e., comparison of EPA Method 5 front half with EPA Method 5 front and back halves);

3. Test series of controlled emissions for which the control device is not specified;

4. Test series in which the source process is not clearly identified and described; and

5. Test series in which it is not clear whether the emissions were measured before or after the control device.

Test data sets that were not excluded were assigned a quality rating. The rating system used was that specified by EIB for preparing AP-42 sections. The data were rated as follows:

A--Multiple tests that were performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily conform to the methodology specified in EPA reference test methods, although these methods were used as a guide for the methodology actually used.

B--Tests that were performed by a generally sound methodology, but lack enough detail for adequate validation.

C--Tests that were based on an untested or new methodology or that lacked a significant amount of background data.

D--Tests that were based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

The following criteria were used to evaluate source test reports for sound methodology and adequate detail:

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures conformed to a generally acceptable methodology. If actual procedures deviated from accepted methods, the deviations are well documented. When this occurred, an evaluation was made of the extent to which such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data are documented in the report, and any variations in the sampling and process operation are noted. If a large spread between test results cannot be explained by information contained in the test report, the data are suspect and are given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those (if any) specified by EPA to establish equivalency. The depth of review of the calculations was dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn was based on factors such as consistency of results and completeness of other areas of the test report.

3.3 EMISSION FACTOR QUALITY RATING SYSTEM

The quality of the emission factors developed from analysis of the test data was rated utilizing the following general criteria:

A--Excellent: Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough so that variability within the source category population may be minimized.

B--Above average: Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industries. The source category is specific enough so that variability within the source category population may be minimized.

C--Average: Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry. In addition, the source category is specific enough so that variability within the source category population may be minimized.

D--Below average: The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of the emission factor are noted in the emission factor table.

E--Poor: The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population. Limitations on the use of these factors are always noted.

The use of these criteria is somewhat subjective and depends to an extent upon the individual reviewer. Details of the rating of each candidate emission factor are provided in Chapter 4 of this report.

REFERENCES FOR SECTION 3

1. *Technical Procedures for Developing AP-42 Emission Factors and Preparing AP-42 Sections, EPA-454/B-93-050*, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC, October 1993.

4.0 AP-42 SECTION DEVELOPMENT

4.1 REVISIONS TO SECTION NARRATIVE

The revised AP-42 section described in this report replaces the September 1991 portland cement manufacturing section of AP-42. The process description and emissions and controls discussion in the previous version had major flaws. Specifically, components of the process other than pyroprocessing were not described (although emission factors were presented for other operations), the different types of dry processes (long dry kiln, dry kiln with preheater, and dry kiln with preheater/precalciner) were not clearly delineated, and the use of waste fuels by the industry was not discussed. Information contained in the recently updated Air Pollution Engineering manual and materials supplied by the PCA on industry characteristics and CO_2 emissions were used to update the discussion.

4.2 POLLUTANT EMISSION FACTOR DEVELOPMENT

A total of 80 documents were reviewed in the process of developing emission factors for this revision to the AP-42 section on portland cement manufacturing. Emission factors were developed from the data presented in 62 of these references. A list of the references used to develop emission factors is presented in Table 4-1. The majority of these documents were emission test reports. However, several test report summaries and other technical reports containing emission data also were reviewed. Approximately 40 of the references were provided by the PCA for the 1991 update of the portland cement kiln SO_2 and NO_x emission factors in AP-42. These references were a combination of full test reports, excerpts from test reports, and tabular data summaries, and the level of supporting data on testing procedures and process operations varied considerably among these references. Many of the remaining reports were taken from the existing background file for the AP-42 section. Other references reviewed include reports of tests sponsored by EPA to determine the emission characteristics of burning hazardous waste in cement kilns; tests to demonstrate compliance with the boiler and industrial furnace (BIF) regulations of 40 CFR Part 266 for using hazardous waste as a supplemental fuel; and a test to satisfy the requirements of California AB 2588 ("Hot Spots").

The data compiled and the emission factors developed from the data are presented in Tables 4-2 to 4-7, which summarize the data on wet process kilns, long dry process kilns, preheater kilns, preheater/precalciner kilns, clinker coolers, and other processes, respectively. These tables specify the type of pollutant; control device; number of test runs; minimum, maximum, and average emission factors for each test; data rating; and reference number for each set of test data reviewed. No data were available on emissions from semidry process kilns.

As has been the practice in previous versions of AP-42, the emission factors for portland cement kilns presented in Tables 4-2 to 4-5 are expressed in units of mass of pollutant emitted in kg (lb) per mass of clinker produced in Mg (ton). Nine of the 56 references from which kiln emission factors were developed provided process rates in terms of clinker production; 25 references provided process rates in terms of both raw material feed and clinker production; and the remaining 22 references provided process rates on the basis of raw material feed. From those references in which both feed and production rates are provided, an average feed-to-production ratio was determined for each type of kiln. These average feed-to-production ratios are as follows: 1.69 for wet process kilns, 1.63 for long dry process kilns, 1.72 for dry preheater process kilns, and 1.70 for dry preheater/precalciner process kilns. These ratios were rounded to 1.6 for long dry process kilns and 1.7 for the other three types of kilns. For the kiln emission

factors developed from references for which only feed rates were provided, these ratios were used to convert emission factors from a feed basis to a clinker production basis. Emission factors for processes other than kilns are presented in Tables 4-6 and 4-7 in units of mass of pollutant emitted per mass of material feed.

Particle size data for portland cement manufacturing processes have not been revised from the previous version of AP-42 because new data were not available, and no problems were found with the methodology and analysis used to develop the particle size data for the previous version of AP-42. A detailed discussion of how the particle size data were developed for the section can be found in Reference 79, which is the background report for the October 1986 revision to the PM emission factors for the portland cement manufacturing section of AP-42. Tables 4-8 and 4-9 summarize the particle size data from Reference 79 for portland cement kilns and clinker coolers, respectively. These particle size data also were used to develop PM-10 emission factors for kilns and clinker coolers.

4.2.1 Review of Specific Data Sets

This section includes descriptions of each reference that was reviewed as part of this revision to AP-42 Section 11.6. A list of the references used to develop emission factors is presented in Table 4-1.

4.2.1.1 Reference 1. This report documents measurements of filterable PM, condensible inorganic PM, CO_2, and NO_x emissions from a gas-fired rotary kiln, and filterable PM and condensible inorganic PM emissions from a clinker cooler. A trace metal analysis was also conducted on the total PM catches from one of the kiln runs and one of the clinker cooler runs. The emission test was sponsored by EPA as part of the development of new source performance standards (NSPS) for portland cement plants and was conducted in 1971. The plant uses the wet process, and process rates were provided on the basis of slurry feed rate. Kiln and clinker cooler emissions are controlled with ESP's, and only controlled emissions were measured.

Particulate matter emissions were measured using Method 5 (front and back half), and NO_x emissions were measured using Method 7. Carbon dioxide emissions were measured using an infrared analyzer. The report does not specify the type of analysis used to quantify trace metal concentrations, although it does state that the analysis was conducted by EPA. Three PM runs and four NO_x runs were conducted.

Emission factors were developed for PM and NO_x emissions and for emissions of the following trace metals: beryllium, (Be), V, Mn, Ni, Cr, iron (Fe), Cu, and strontium (Sr). The PM samples also were analyzed for cadmium, arsenic, antimony, and lead, but these elements were not detected. Insufficient information was available to develop emission factors for CO_2 emissions. The test report noted that a number of upsets occurred during the testing of the kiln.

The clinker cooler emission data for filterable and condensible PM are rated B. The test methodology was sound, and no problems were reported, but the report lacked adequate documentation for a higher rating. The kiln PM and NO_x emission data are rated C. Although the methodology was sound, because of the upsets that occurred during testing and the lack of adequate documentation, a higher rating is not justified. The trace metal data are unrated because only one run was conducted and the analytical method was not specified.

TABLE 4-1. SUMMARY OF EMISSION TEST REPORTS AND SUMMARIES USED

Company name	Plant location	Type of process	Sources tested	Pollutants	Year	Ref. No.
Maule Industries	Hiahleah, FL	wet	clinker cooler	PM, metals	1971	1
			kiln	PM, metals		
Ideal Cement	Seattle, WA	wet	clinker cooler	PM, metals	1971	2
			kiln	PM, metals		
Ideal Cement	Castle Hayne, NC	wet	finish mill air separator	PM	1971	3
			finish grinding mill	PM		
Dragon Cement	Northampton, PA	dry	kiln	PM, SOx, Hg, CO2	1971	4
Ideal Cement	Houston, TX	wet	clinker cooler	PM	1971	5
			finish grinding mill	PM		
Giant Portland Cement	Harleyville, SC	wet	kiln	PM, SO2, NOx, Hg	1971	6
Oregon Portland Cement	Lake Oswego, OR	wet	kiln	PM, SO2	1971	7
Ideal Cement	Tijeras, NM	dry	raw mill weigh hopper	PM, metals	1971	8
			raw mill	PM, metals		
			raw mill air separator	PM, metals		
			finish mill weigh hopper	PM, metals		
			finish mill	PM		
			finish mill air separator	PM, metals		
Arizona Portland Cement	Rillito, AZ	NA	primary crushing	PM	1974	9
			primary screening	PM		
			limestone transfer	PM		
			secondary screening and crushing	PM		
Monarch Cement	Humboldt, KS	preheater	kiln	PM	1981	10
Ideal Basic Industries	Ada, OK	wet	kiln	PM	1981	11
Lone Star Industries	Nazareth, PA	dry	kiln	PM, SO2	1977	12

TABLE 4-1. (continued)

Company name	Plant location	Type of process	Sources tested	Pollutants	Year	Ref. No.
Lone Star Industries	Greencastle, IN	wet	kiln	PM, SO2	1979	13
Lone Star Cement	Roanoke, VA	dry, wet	kiln	PM, CO2	1980	14
Oklahoma Cement	Pryor, OK	dry	clinker cooler	PM	1980	15
Oklahoma Cement	Pryor, OK	dry	kiln	PM, SO2, CO2	1980	16
Lone Star Industries	Sweetwater, TX	preheater	kiln	SO2, SO3, CO2	1980	17
Lone Star Industries	New Orleans, LA	wet	kiln	PM, SO2, SO3, NH4, Cl, K, Na, SO4, CO2	1980	18
Lone Star Industries	Bonner Springs, KS	wet	kiln	PM, SO2, NOx, CO2	1981	19
Lehigh Portland Cement	Mason City, IO	dry	clinker cooler	PM, CO2	1983	20
California Portland Cement	Mojave, CA	precalciner	kiln	SO2, NOx, CO, CO2	1983	21
Lehigh Portland Cement	Waco, TX	NS	kiln	PM, SO2, NOx, CO2	1983	23
			clinker cooler	PM		
California Portland Cement	Mojave, CA	precalciner	kiln	PM, SO2, SO3, NOx CO, CO2, TOC	1984	24
			clinker cooler	PM		
Leeds Portland Cement	Leeds, AL	preheater	kiln	PM, CO2	1984	25
			clinker cooler	PM, CO2		
Lehigh Portland Cement	Cementon, NY	wet	kiln	PM, SO2, CO2	1984	26
CalMatCo	Mojave, CA	precalciner	kiln	PM, SO2, SO3, NOx CO, CO2, TOC	1985	27
			clinker cooler	PM		
Lonestar Florida Holding	Miami, FL	wet	kiln	PM, SO2, NOx, CO2	1985	28
Lonestar Florida/Pennsuco	Miami, FL	wet	kiln	PM, SO2, NOx, CO2	1981	29
Lonestar Florida/Pennsuco	Miami, FL	wet	kiln	PM, SO2, NOx, CO2	1981	30
Lone Star Cement	Davenport, CA	precalciner	kiln	PM, SO2, NOx, CO CO2	1985	31
CalMatCo	Colton, CA	dry	kiln	NOx	1987	35
Riverside Cement	Crestmore, CA	dry	kiln	SO2, NOx, CO	1981	36
				NOx	1985	
Lafarge Corp.	Alpena, MI	dry	kiln	PM, SO2, NOx, TOC	1989	37

TABLE 4-1. (continued)

Company name	Plant location	Type of process	Sources tested	Pollutants	Year	Ref. No.
Southwestern Portland Cement	Black Mountain, CA	dry	kiln	SO2, NOx, CO, CO2	1984	39
Alpha Portland Cement	Cementon, NY	wet	kiln	PM, SO2, HCl	1982	40
Lone Star Industries	New Orleans, LA	wet	kiln	PM, SO2, SO4, NH4, Cl, K, Na,	1982	42
Lone Star Industries	New Orleans, LA	wet	kiln	PM, SO2, SO4, NH4, Cl, K, Na, F, NOx	1982	43
Lone Star Industries	New Orleans, LA	wet	kiln	PM, SO2, SO4, NH4, Cl, Na, CO2	1982	44
Southwestern Portland Cement	Victorville, CA	wet	kiln	SO2, NOx, CO, CO2	1980	48
Ash Grove Cement West	Durkee, OR	precalciner	kiln	NOx	1987	49
Calaveras Cement	Redding, CA	precalciner	kiln	SO2, NOx	1981	50
Texas Cement	Buda, TX	precalciner	kiln	PM, SO2, NOx	1986	51
Southwestern Portland Cement	Fairborn, OH	preheater	kiln	PM, SO2, CO2	1986	52
Florida Mining and Materials	Brooksville, FL	preheater	kiln	PM, SO2, NOx	1982	53
				PM, SO2	1983	
				PM, SO2, NOx	1984	
				PM, SO2, NOx	1985	
				PM, SO2, NOx, CO2	1986	
				PM, SO2, NOx	1987	
				PM, NOx, CO2	1988	
				PM, SO2, NOx, CO2	1989	
Southwestern Portland Cement	Kosmosdale, KY	preheater	kiln	PM, SO2, NOx, CO CO2, TOC, HCl	1989	54
Southwestern Portland Cement	Odessa, TX	preheater	kiln	PM, SO2, SO3, NOx CO2	1983	55
Ash Grove Cement West	Leamington, UT	precalciner	kiln	PM, SO2, NOx, CO2	1989	56

TABLE 4-1. (continued)

Company name	Plant location	Type of process	Sources tested	Pollutants	Year	Ref. No.
CalMatCo	Colton, CA	precalciner	kiln	PM, SO2, NOx	1983	57
				PM, SO2, NOx, CO SO4, TOC	1984	
				PM, SO2, NOx, CO SO4, TOC	1985	
				PM, SO2, NOx, CO SO4, TOC	1986	
				PM, SO2, NOx, CO SO4, TOC	1987	
				PM, SO2, NOx, CO SO4, TOC	1988	
				PM, SO2, NOx, CO SO4, TOC	1989	
Marquette Cement	Cape Girardeau, MO	precalciner	kiln	SO2	1982	58
Lone Star Industries	Cape Girardeau, MO	precalciner	kiln	SO2	1983	59
Ash Grove Cement West	Leamington, UT	precalciner	kiln	PM, NOx, CO2	1985	60
Southwestern Portland Cement	Victorville, CA	precalciner	kiln	PM, SO2, NOx, CO, CO2, TOC	1985	61
			clinker cooler	PM		
			raw mill	PM		
			finish mill	PM		
Southwestern Portland Cement	Victorville, CA	precalciner	kiln	PM, SO2, NOx, CO, CO2	1985	62
			raw mill	PM		
			raw mill feed belt	PM		
			finish mill	PM		
			finish mill feed belt	PM		
Southwestern Portland Cement	Victorville, CA	precalciner	kiln	PM, SO2, NOx, CO, CO2	1987	63
Southwestern Portland Cement	Victorville, CA	precalciner	kiln	PM, SO2, NOx, CO CO2, NH3, HCl	1987	64

TABLE 4-1. (continued)

Company name	Plant location	Type of process	Sources tested	Pollutants	Year	Ref. No.
Ash Grove	Louisville, NE	precalciner	kiln	NOx, CO, CO2, 20 organics	1990	65
Continental	Hannibal, MO	wet	kiln	SO2, NOx, CO, CO2, 25 organics	1990	66
Lonestar Florida/Pennsuco	Miami, FL	wet	kiln	PM, CO2	1980	67
Lone Star Industries	Sweetwater, TX	preheater	kiln	PM, CO2	1980	69
Kaiser Cement	Walnut Creek, CA	precalciner	kiln	HCl, CO2, 6 metals, 24 organics	1990	74
Lone Star Industries	Cape Girardeau, MO	precalciner	kiln	PM, CO, CO2, TOC, HCl, Cl, 11 metals	1992	76
Essrock Materials	Frederick, MD	wet	kiln	PM, SO2, NOx, CO THC, 7 metals, 15 organics	1991	77
Lone Star Industries	Oglesby, IL	dry	kiln	PM, SO2, NOx, CO THC, HCl, 12 metals, 14 organics	1984	78

TABLE 4-2. SUMMARY OF TEST DATA FOR PORTLAND CEMENT WET PROCESS KILNS

Pollutant	Type of control	No. of runs(a)	sion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.		
COAL-FIRED ROTARY KILNS												
filterable PM	none	4	550	700	630	1,100	1,400	1,250	D	11	1	1
filterable PM	none	6	63	73	65	125	145	130	B	13		
filterable PM	none	4	55	75	65	110	150	130	B	19	2	1
filterable PM	none	3a	100	230	180	200	450	350	C	30	3	1
filterable PM	ESP	2	0.053	0.086	0.069	0.11	0.17	0.14	C	11	6	1
filterable PM	ESP	3a	0.034	0.079	0.050	0.068	0.16	0.10	C	67	6.5	1
filterable PM	ESP	3	0.00049	0.19	0.075	0.00098	0.38	0.15	C	13	7	1
filterable PM	ESP	3b	0.13	0.26	0.18	0.26	0.51	0.36	B	18	8	1
filterable PM	ESP	3c	0.17	0.20	0.19	0.34	0.41	0.37	B	18	9	1
filterable PM	ESP	7d	0.14	1.6	0.70	0.27	3.2	1.4	B	19	10	1
filterable PM	ESP	14	0.22	1.1	0.60	0.44	2.1	1.2	B	19	11	1
filterable PM	ESP	4d	0.17	0.95	0.42	0.33	1.9	0.83	B	19	12	1
filterable PM	ESP	3e	0.070	0.10	0.075	0.14	0.19	0.15	C	26	13	1
filterable PM	ESP	3a	0.10	0.13	0.12	0.20	0.26	0.23	B	28	14	1
filterable PM	ESP	3a	0.080	0.13	0.10	0.16	0.26	0.20	C	29	15	1
filterable PM	ESP	3a	0.060	0.13	0.10	0.12	0.26	0.19	C	30	16	1
filterable PM	ESP	3e	0.50	0.55	0.55	1.0	1.1	1.1	C	40	17	1
filterable PM	ESP	3b	0.018	0.37	0.16	0.04	0.73	0.32	B	42	18	1
filterable PM	ESP	3c	0.038	0.15	0.11	0.08	0.31	0.22	B	42	19	1
filterable PM	ESP	3b	0.22	0.29	0.25	0.44	0.58	0.49	B	43	20	1
filterable PM	ESP	3c	0.065	0.10	0.084	0.13	0.20	0.17	B	44	21	1
filterable PM	FF	3	0.21	0.26	0.23	0.43	0.53	0.46	C	7	24	1
filterable PM	(b)	2	0.034	0.17	0.10	0.07	0.33	0.20	C	14	25	1
condensible inorg. PM	ESP	3	0.050	0.17	0.11	0.10	0.33	0.21	B	13	28	1
condensible inorg. PM	FF	3	0.026	0.25	0.10	0.053	0.49	0.20	C	7	30	1
condensible inorg. PM	(b)	2	0.10	0.19	0.14	0.20	0.37	0.29	C	14	31	1
SO2	none	3a	2.1	3.9	3.0	4.2	7.7	6.0	C	30		
SO2	ESP	3f	0.55	2.4	1.2	1.1	4.7	2.3	B	13	34	1

TABLE 4-2. (Continued)

Pollutant	Type of control	No. runs(a)	sion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.			
SO2	ESP	3f	5.5	7.0	6.0	11	14	12	B	13	35	1	
SO2	ESP	3c	1.8	3.1	2.6	3.6	6.3	5.3	C	18	36	1	
SO2	ESP	3b	0.26	1.8	1.0	0.53	3.6	2.0	C	18	37	1	
SO2	ESP	6d	2.1	15	11	4.1	30	21	B	19	38	1	
SO2	ESP	16	2.0	11	5.5	3.9	22	11	B	19	39	1	
SO2	ESP	8d	3.5	10	6.0	6.9	20	12	B	19	40	1	
SO2	ESP	3e	8.0	10	9.0	16	20	18	C	26	41	1	
SO2	ESP	3a	2.1	2.3	2.2	4.2	4.5	4.4	B	28	42	1	
SO2	ESP	3a	2.2	3.5	2.8	4.4	6.9	5.5	C	29	43	1	
SO2	ESP	3a	1.9	3.3	2.7	3.8	6.5	5.4	C	30	44	1	
SO2	ESP	3e	1.3	1.6	1.4	2.5	3.1	2.8	C	40	45	1	
SO2	ESP	3c	2.2	3.2	2.8	4.4	6.5	5.6	C	42	46	1	
SO2	ESP	3b	2.1	3.6	2.8	4.3	7.1	5.6	C	42	47	1	
SO2	ESP	3c	6.8	8.5	8.0	13.6	17	16	C	44	48	1	
SO2	ESP	1	NA	NA	13	NA	NA	25	NR	65			
SO2	FF	4	0.085	0.42	0.20	0.17	0.83	0.41	D	7	51	1	
NOx	ESP	6d	0.24	2.1	0.90	0.47	4.1	1.8	B	19			
NOx	ESP	12	1.7	4.7	3.0	3.4	9.3	6.0	B	19			
NOx	ESP	2d	2.5	2.7	2.6	4.9	5.3	5.1	C	19			
NOx	ESP	3a	3.2	3.5	3.4	6.3	6.9	6.7	B	28	53	1	
NOx	ESP	12a	1.6	4.2	3.2	3.2	8.4	6.4	C	29	54	1	
NOx	ESP	12a	2.5	4.7	3.4	4.9	9.3	6.8	C	30	55	1	
NOx	ESP	3b	1.7	2.9	2.1	3.4	5.8	4.3	B	43	56	1	
NOx	ESP	12c	1.4	2.7	1.9	2.9	5.4	3.7	B	43	57	1	
NOx	ESP	1	NA	NA	10	NA	NA	20	NR	65			
CO	ESP	1	NA	NA	1.3	NA	NA	2.7	NR	65			
CO2	ESP	3c	1,100	1,100	1,100	2,100	2,200	2,200	B	18	59	0	{EDIT}
CO2	ESP	3a	290	320	310	578	630	610	C	67	59.5	1	{HOME}
CO2	ESP	3b	950	1,000	1,000	1,900	2,000	2,000	B	18	60	1	@round(,-2)~

TABLE 4-2. (Continued)

Pollutant	Type of control	No. runs(a)	sion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.			
CO2	ESP	4f	1,100	1,500	1,250	2,200	2,900	2,500	B	19			
CO2	ESP	8f	1,200	2,600	1,700	2,400	5,100	3,300	B	19			
CO2	ESP	8	650	2,200	1,100	1,300	4,400	2,200	B	19			
CO2	ESP	3e	800	950	900	1,600	1,900	1,800	C	26	61	1	{END}
CO2	ESP	3a	1,000	1,200	1,100	2,000	2,300	2,100	B	28	62	1	
CO2	ESP	3a	410	450	430	820	890	850	C	29	63	1	
CO2	ESP	6a	410	490	450	810	970	890	C	30	64	1	
CO2	ESP	3c	1,100	1,300	1,200	2,200	2,500	2,300	C	44	65	1	
CO2	ESP	1	NA	NA	2,200	NA	NA	4,400	NR	65			
CO2	(b)	2	26	950	490	51	1,900	970	D	14	67	1	
Be	ESP	1	NA	NA	2.2E-006	NA	NA	4.4E-006	NR	2	68	1	
Cd	ESP	1	NA	NA	0.00019	NA	NA	0.00037	NR	2	69	1	
Cl	ESP	3b	0.12	0.23	0.17	0.24	0.46	0.34	C	18	70	1	
Cl	ESP	3c	0.15	0.29	0.25	0.31	0.58	0.49	C	18	71	1	
Cl	ESP	3b	0.15	0.48	0.31	0.31	0.97	0.61	C	42	72	1	
Cl	ESP	3c	0.42	0.62	0.52	0.83	1.2	1.0	C	42	73	1	
Cl	ESP	3c	ND	ND	0.55	ND	ND	1.1	C	43	74	1	
Cl	ESP	3c	0.37	0.50	0.44	0.73	1.0	0.88	C	44	75	1	
Cr	ESP	1	NA	NA	0.00011	NA	NA	0.00022	NR	2	77	1	
Cu	ESP	1	NA	NA	0.00022	NA	NA	0.00044	NR	2	79	1	
F	ESP	3c	ND	ND	0.00045	ND	ND	0.00090	C	43	80	1	
Fe	ESP	1	NA	NA	0.017	NA	NA	0.033	NR	2	82	1	
HCl	ESP	3	0.016	0.036	0.024	0.031	0.071	0.047	C	40	84	1	
K	ESP	3b	0.013	0.026	0.020	0.026	0.053	0.041	B	18	85	1	
K	ESP	3c	0.016	0.025	0.020	0.032	0.049	0.041	B	18	86	1	
K	ESP	3b	0.00060	0.00082	0.00068	0.0012	0.0016	0.0014	B	42	87	1	
K	ESP	3c	6.8E-005	0.0012	0.00047	0.00014	0.0024	0.00094	B	42	88	1	
K	ESP	3c	ND	ND	0.00060	ND	ND	0.0012	C	43	89	1	
Mn	ESP	1	NA	NA	0.00022	NA	NA	0.00044	NR	2	91	1	

TABLE 4-2. (Continued)

Pollutant	Type of control	No. runs(a)	sion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.		
NH4	ESP	3c	0.010	0.023	0.015	0.020	0.046	0.031	C	18	92	1
NH4	ESP	3b	0.0065	0.0094	0.0078	0.013	0.019	0.016	C	18	93	1
NH4	ESP	3b	0.026	0.053	0.037	0.053	0.11	0.073	B	42	94	1
NH4	ESP	3c	0.084	0.13	0.11	0.17	0.26	0.22	B	42	95	1
NH4	ESP	3	ND	ND	0.094	ND	ND	0.19	C	43	96	1
NH4	ESP	3	0.11	0.14	0.12	0.22	0.29	0.24	C	44	97	1
NO3	ESP	3	ND	ND	0.0023	ND	ND	0.0046	C	43	98	1
Na	ESP	3	0.015	0.027	0.021	0.031	0.054	0.043	B	18	99	1
Na	ESP	3	0.022	0.024	0.023	0.044	0.048	0.046	B	18	100	1
Na	ESP	3	0.00020	0.0045	0.0016	0.0004	0.0090	0.0032	B	42	101	1
Na	ESP	3	3.7E-003	0.0057	0.0044	0.0073	0.011	0.0088	B	42	102	1
Na	ESP	3	ND	ND	0.0010	ND	ND	0.0020	C	43	103	1
Na	ESP	3	0.052	0.094	0.077	0.10	0.19	0.15	C	44	104	1
Ni	ESP	1	NA	NA	0.00022	NA	NA	0.00044	NR	2	106	1
Pb	ESP	1	NA	NA	0.0044	NA	NA	0.0088	NR	2	108	1
SO3	ESP	3c	0.026	0.085	0.064	0.053	0.17	0.13	C	18	109	1
SO3	ESP	3b	0.016	0.029	0.020	0.032	0.058	0.041	C	18	110	1
SO4	ESP	3b	0.071	0.082	0.076	0.14	0.16	0.15	B	18	111	1
SO4	ESP	3c	0.010	0.022	0.017	0.020	0.044	0.034	B	18	112	1
SO4	ESP	3b	0.16	0.22	0.19	0.32	0.44	0.37	B	42	113	1
SO4	ESP	3c	0.094	0.16	0.12	0.19	0.32	0.24	B	42	114	1
SO4	ESP	3c	ND	ND	0.12	ND	ND	0.24	C	43	115	1
SO4	ESP	3c	0.025	0.037	0.030	0.049	0.073	0.060	C	44	116	1
V	ESP	1	NA	NA	6.7E-005	NA	NA	0.00013	NR	2	119	1
Zn	ESP	1	NA	NA	0.0094	NA	NA	0.019	NR	2	120	1
Acrolein	ESP	1	NA	NA	0.00094	NA	NA	0.0019	NR	65	0.00055	
Acetone	ESP	1	NA	NA	0.0012	NA	NA	0.0024	NR	65	0.00072	
Methylene chloride	ESP	1	NA	NA	0.00043	NA	NA	0.00085	NR	65	0.00025	
Acrylonitrile	ESP	1	NA	NA	0.0016	NA	NA	0.0032	NR	65	0.00093	

TABLE 4-2. (Continued)

Pollutant	Type of control	No. runs(a)	sion factor, kg/Mg Minimum	Maximum	Emission factor, lb/ton Average	Minimum	Maximum	Average	Data rating	Ref. No.		
t-1,2-Dichloroethane	ESP	1	NA	NA	2.4E-007	NA	NA	4.8E-007	NR	65	0.0000001	
1,1 Dichloroethane	ESP	1	NA	NA	1.2E-006	NA	NA	2.3E-006	NR	65	0.0000007	
Methyl ethyl ketone	ESP	1	NA	NA	0.00026	NA	NA	0.00051	NR	65	0.00015	
Chloroform	ESP	1	NA	NA	5.3E-005	NA	NA	0.00011	NR	65	0.000031	
1,1,1-Trichloroethane	ESP	1	NA	NA	4.6E-005	NA	NA	9.2E-005	NR	65	0.000027	
Carbon tetrachloride	ESP	1	NA	NA	2.9E-006	NA	NA	5.8E-006	NR	65	0.0000017	
Benzene	ESP	1	NA	NA	0.0029	NA	NA	0.0058	NR	65	0.0017	
1,2-Dichloroethane	ESP	1	NA	NA	2.0E-005	NA	NA	4.1E-005	NR	65	0.000012	
Trichloroethene	ESP	1	NA	NA	2.0E-005	NA	NA	4.1E-005	NR	65	0.000012	
1,2-Dichloropropane	ESP	1	NA	NA	2.9E-006	NA	NA	5.8E-006	NR	65	0.0000017	
p-Dioxane	ESP	1	NA	NA	0.00016	NA	NA	0.00032	NR	65	0.000093	
Bromodichloromethane	ESP	1	NA	NA	2.9E-005	NA	NA	5.8E-005	NR	65	0.000017	
Toluene	ESP	1	NA	NA	0.00094	NA	NA	0.0019	NR	65	0.00055	
t-1,3-Dichloropropene	ESP	1	NA	NA	1.7E-006	NA	NA	3.4E-006	NR	65	0.000001	
1,1,2-Trichloroethane	ESP	1	NA	NA	2.0E-005	NA	NA	4.1E-005	NR	65	0.000012	
Tetrachloroethene	ESP	1	NA	NA	1.1E-005	NA	NA	2.1E-005	NR	65	0.0000062	
Dibromochloromethane	ESP	1	NA	NA	3.6E-006	NA	NA	7.1E-006	NR	65	0.0000021	
Chlorobenzene	ESP	1	NA	NA	0.00019	NA	NA	0.00037	NR	65	0.00011	
Ethylbenzene	ESP	1	NA	NA	0.00015	NA	NA	0.00030	NR	65	0.000089	
Bromoform	ESP	1	NA	NA	6.5E-006	NA	NA	1.3E-005	NR	65	0.0000038	
1,1,2,2-Tetrachrloroethane	ESP	1	NA	NA	5.8E-005	NA	NA	0.00012	NR	65	0.000034	
Benzyl alcohol	ESP	1	NA	NA	0.0041	NA	NA	0.0082	NR	65	0.0024	
Benzoic acid	ESP	1	NA	NA	0.0058	NA	NA	0.012	NR	65	0.0034	
Naphthalene	ESP	1	NA	NA	0.00085	NA	NA	0.0017	NR	65	0.0005	
2-Methylnaphthalene	ESP	1	NA	NA	0.00029	NA	NA	0.00058	NR	65	0.00017	
Phenanthrene	ESP	1	NA	NA	0.00012	NA	NA	0.00024	NR	65	0.000072	
CDD/CDF (total)	ESP	1	NA	NA	6.3E-007	NA	NA	1.3E-006	NR	65	0.0000004	
GAS-FIRED ROTARY KILNS												
filterable PM	ESP	3	0.54	1.5	1.0	1.1	3.1	2.0	C	1	4	2 gas-fired

TABLE 4-2. (Continued)

Pollutant	Type of control	No. runs(a)	sion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.			
filterable PM	ESP	2	0.72	0.78	0.75	1.4	1.6	1.5	C	2	5	2	gas-fired
filterable PM	FF	1	NA	NA	0.46	NA	NA	0.92	NR	6	23	2	gas
condensible inorg. PM	ESP	3	0.054	0.16	0.10	0.11	0.32	0.20	C	1	26	2	gas-fired
condensible inorg. PM	ESP	2	0.063	0.09	0.075	0.13	0.17	0.15	C	2	27	2	gas-fired
SO2	FF	2	4.8	6.4	5.6	9.7	13	11	D	6	49	2	gas
NOx	ESP	4	0.71	2.2	1.4	1.4	4.4	2.9	C	1	52	2	gas-fired
NOx	FF	2	1.6	4.3	3.0	3.2	8.5	6.0	D	6	58	2	gas
Cr	ESP	1	NA	NA	0.0020	NA	NA	0.0039	NR	1	76	2	gas-fired
Cu	ESP	1	NA	NA	0.00015	NA	NA	0.00031	NR	1	78	2	gas-fired
Fe	ESP	1	NA	NA	0.0062	NA	NA	0.012	NR	1	81	2	gas-fired
Hg	FF	2	1.3E-005	2.6E-005	2.0E-005	2.6E-005	5.3E-005	3.9E-005	D	6	83	2	gas
Mn	ESP	1	NA	NA	7.7E-005	NA	NA	0.00015	NR	1	90	2	gas-fired
Ni	ESP	1	NA	NA	0.0013	NA	NA	0.0026	NR	1	105	2	gas-fired
Pb	ESP	1	NA	NA	0.00048	NA	NA	0.00097	NR	1	107	2	gas-fired
Sr	ESP	1	NA	NA	0.0017	NA	NA	0.0034	NR	1	117	2	gas-fired
V	ESP	1	NA	NA	8.2E-005	NA	NA	0.00016	NR	1	118	2	gas-fired
OIL-FIRED ROTARY KILNS													
condensible inorg. PM	FF	1	NA	NA	0.57	NA	NA	1.1	NR	6	29	3	oil
SO2	none	1	NA	NA	16	NA	NA	32	NR	6	32	3	oil
SO2	FF	2	7.2	11	8.9	14	21	18	D	6	50	3	oil
COAL- AND OIL-FIRED ROTARY KILNS													
filterable PM	ESP	3	0.35	0.46	0.42	0.69	0.91	0.84	B	77	1	4	coal/oil-fired
condensible inorg. PM	ESP	3	0.021	0.025	0.024	0.042	0.050	0.047	B	77	2	4	coal/oil-fired
SO2	ESP	3	0.55	2.0	1.2	1.1	4.0	2.3	B	77	3	4	coal/oil-fired
NOx	ESP	3	8.5	11	10	17	22	20	B	77	4	4	coal/oil-fired
CO	ESP	3	0.046	0.080	0.060	0.092	0.16	0.12	B	77	5	4	coal/oil-fired
CO2	ESP	3	1,300	1,400	1,300	2,500	2,700	2,600	B	77	6	4	coal/oil-fired
TOC	ESP	3	0.014	0.015	0.014	0.027	0.029	0.028	B	77	6.5	4	coal/oil-fired
Ba	ESP	3	0.00014	0.00025	0.00018	0.00027	0.00049	0.00035	B	77	7	4	coal/oil-fired

TABLE 4-2. (Continued)

Pollutant	Type of control	No. runs(a)	sion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.		
Cd	ESP	3	2.7E-006	6.5E-006	4.2E-006	0.0000054	0.000013	0.0000083	B	77	7	4 coal/oil-fired
Cr	ESP	2	1.6E-006	6.0E-006	3.9E-006	0.0000032	0.000012	0.0000077	C	77	7	4 coal/oil-fired
Hg	ESP	3	7.5E-005	0.00014	0.00011	0.00015	0.00027	0.00022	B	77	7	4 coal/oil-fired
Ni	ESP	1	NA	NA	1.4E-005	NA	NA	0.000027	NR	77	7	4 coal/oil-fired
Pb	ESP	3	0.00021	0.00048	0.00036	0.00042	0.00096	0.00071	B	77	7	4 coal/oil-fired
Zn	ESP	3	0.00019	0.00037	0.00027	0.00038	0.00073	0.00054	B	77	7	4 coal/oil-fired
2-butanone	ESP	3	3.7E-006	2.9E-005	2.0E-005	0.0000073	0.000058	0.000039	B	77	8	4 coal/oil-fired
acetone	ESP	3	4.7E-005	0.00033	0.00019	0.000093	0.00065	0.00037	B	77	8	4 coal/oil-fired
benzene	ESP	3	0.0014	0.0019	0.0016	0.0027	0.0037	0.0031	B	77	8	4 coal/oil-fired
benzoic acid	ESP	3	0.0014	0.0021	0.0018	0.0028	0.0042	0.0035	B	77	8	4 coal/oil-fired
bis(2-ethylhexyl)phthalate	ESP	3	3.1E-005	7.0E-005	4.8E-005	0.000061	0.00014	0.000095	B	77	8	4 coal/oil-fired
bromomethane	ESP	2	1.5E-005	2.9E-005	2.2E-005	0.000029	0.000058	0.000043	C	77	8	4 coal/oil-fired
carbon disulfide	ESP	3	5.0E-005	6.0E-005	5.5E-005	0.00010	0.00012	0.00011	B	77	8	4 coal/oil-fired
chlorobenzene	ESP	2	5.5E-006	1.1E-005	8.0E-006	0.000011	0.000021	0.000016	C	77	8	4 coal/oil-fired
chloromethane	ESP	3	8.5E-005	0.00029	0.00019	0.00017	0.00057	0.00038	B	77	8	4 coal/oil-fired
di-n-butylphthalate	ESP	3	1.5E-005	2.4E-005	2.1E-005	3.0E-005	0.000047	0.000041	B	77	8	4 coal/oil-fired
ethylbenzene	ESP	3	5.5E-006	1.5E-005	9.5E-006	0.000011	0.000029	0.000019	B	77	8	4 coal/oil-fired
naphthalene	ESP	3	6.0E-005	0.00015	0.00011	0.00012	0.00029	0.00022	B	77	8	4 coal/oil-fired
phenol	ESP	3	4.5E-005	6.0E-005	5.5E-005	0.000089	0.00012	0.00011	B	77	8	4 coal/oil-fired
toluene	ESP	3	0.00060	0.0014	0.00010	0.0012	0.0028	0.00019	B	77	8	4 coal/oil-fired
xylenes	ESP	3	2.0E-005	0.00012	0.00007	4.0E-005	0.00023	0.00013	B	77	8	4 coal/oil-fired

ESP = electrostatic precipitator.
FF = fabric filter.
TOC = total organic compounds.
NA = not applicable.
NR = not rated.
(a) Multiple tests conducted on the same kiln indicated by a-e.
(b) Cooling tower with multiclone and ESP.

TABLE 4-3. SUMMARY OF TEST DATA FOR PORTLAND CEMENT LONG DRY PROCESS KILNS

Pollutant	Type of control	No. of runs	Emission factor, kg/Mg			Emission factor, lb/ton		
			Minimum	Maximum	Average	Minimum	Maximum	Average
filterable PM	ESP	3	0.12	0.46	0.24	0.24	0.92	0.48
filterable PM	ESP	3	0.065	0.16	0.10	0.13	0.33	0.21
filterable PM	ESP	2	0.600	1.35	0.95	1.2	2.7	1.9
filterable PM	FF	2	0.044	0.049	0.046	0.088	0.10	0.093
filterable PM	FF	3	0.090	0.10	0.10	0.18	0.21	0.20
filterable PM	FF	3	ND	ND	0.10	ND	ND	0.19
filterable PM	(a)	6	0.55	0.80	0.65	1.1	1.6	1.3
filterable PM	(a)	6	0.28	2.0	0.85	0.56	4.0	1.7
filterable PM	(a)	6	0.50	0.80	0.65	1.0	1.6	1.3
condensible inorg. PM	ESP	3	0.18	0.70	0.41	0.37	1.4	0.82
condensible inorg. PM	ESP	3	0.10	0.18	0.13	0.20	0.35	0.26
condensible inorg. PM	FF	2	0.088	0.10	0.10	0.18	0.19	0.19
condensible inorg. PM	FF	3	0.42	0.48	0.44	0.85	0.97	0.89
condensible inorg. PM	(a)	6	0.090	0.20	0.14	0.18	0.39	0.29
condensible inorg. PM	(a)	6	0.0026	0.20	0.10	0.0051	0.41	0.21
condensible inorg. PM	(a)	6	0.10	0.20	0.16	0.20	0.40	0.33
SO2	ESP	12	11	17	14	22	33	27
SO2	ESP	2	0.080	0.011	0.046	0.16	0.022	0.092
SO2	FF	3	1.8	3.5	2.7	3.7	7.0	5.4
SO2	FF	3	0.080	0.40	0.19	0.16	0.81	0.38
SO2	FF	3	0.13	0.27	0.20	0.26	0.54	0.40
SO2	FF	6	1.9	5.0	3.4	3.8	10	6.7
SO2	FF	5	0.010	0.45	0.12	0.019	0.90	0.24
NOx	FF	2	0.96	1.9	1.4	1.9	3.8	2.9
NOx	FF	3	7.0	7.5	7.0	14	15	14
NOx	FF	3	2.2	7.0	4.6	4.5	14	9.2
NOx	FF	(b)	NA	NA	2.9	NA	NA	5.8

TABLE 4-3. (Continued)

Pollutant	Type of control	No. of runs	Emission factor, kg/Mg			Emission factor, lb/ton		
			Minimum	Maximum	Average	Minimum	Maximum	Average
NOx	FF	3	1.7	2.9	2.2	3.4	5.8	4.3
NOx	FF	6	2.2	3.6	2.8	4.5	7.3	5.5
NOx	ESP	2	3.0	3.3	3.2	6.0	6.6	6.3
NOx	FF	3	3.2	3.4	3.4	6.5	6.9	6.7
NOx	FF	81	1.7	5.0	3.4	3.4	10	6.7
CO	ESP	2	0.10	0.12	0.11	0.20	0.24	0.22
CO	FF	3	0.10	0.10	0.10	0.20	0.20	0.20
CO	FF	1	NA	NA	0.44	NA	NA	0.87
CO2	ESP	2	950	1,000	1,000	1,900	2,000	2,000
CO2	FF	2	360	470	420	720	940	830
CO2	FF	3	850	950	900	1,700	1,900	1,800
CO2	FF	6	750	1,400	1,000	1,500	2,800	2,000
CO2	(a)	6	750	1,200	900	1,500	2,300	1,800
CO2	(a)	6	850	1,400	1,100	1,700	2,800	2,100
CO2	(a)	6	950	1,200	1,100	1,900	2,300	2,100
VOC	FF	3	ND	ND	0.22	ND	ND	0.45
TOC	FF	3	ND	ND	0.024	ND	ND	0.048
TOC	ESP	2	0.0042	0.0046	0.0044	0.0083	0.0093	0.0088
HCl	ESP	2	0.019	0.031	0.025	0.038	0.062	0.050
Al	ESP	2	0.0036	0.0090	0.0065	0.0073	0.018	0.013
As	ESP	2	5.5e-06	7.0e-06	6.5e-06	0.000011	0.000014	0.000013
Ca	ESP	2	0.085	0.16	0.12	0.17	0.31	0.24
Cd	ESP	2	1.6e-05	2.8e-05	2.2e-05	0.000031	0.000056	0.000043
Cr	ESP	1	NA	NA	0.00012	NA	NA	0.00025
Fe	ESP	2	0.0065	0.010	0.0085	0.013	0.021	0.017
Hg	ESP	2	1.6e-06	3.0e-06	2.3e-06	0.0000032	0.0000059	0.0000046
Hg	FF	3	9.6e-06	2.2e-05	1.4e-05	1.9e-05	4.3e-05	2.9e-05

TABLE 4-3. (Continued)

Pollutant	Type of control	No. of runs	Emission factor, kg/Mg			Emission factor, lb/ton		
			Minimum	Maximum	Average	Minimum	Maximum	Average
Mn	ESP	2	0.00032	0.00055	0.00043	0.00063	0.0011	0.00086
Pb	ESP	2	5.0e-05	1.1e-04	8.0e-05	0.00010	0.00021	0.00016
Se	ESP	2	5.0e-05	0.00010	7.5e-05	0.00010	0.00020	0.00015
Ti	ESP	2	3.2e-04	4.8e-05	0.00018	0.00063	0.000096	0.00037
Zn	ESP	2	7.0e-05	3.4e-05	5.0e-05	0.00014	0.000068	0.00010
freon 113	ESP	2	2.3e-05	2.8e-05	2.5e-05	0.000045	0.000055	0.00005
toluene	ESP	2	9.5e-05	0.00016	0.00013	0.00019	0.00033	0.00026
methyl ethyl ketone	ESP	2	8.0e-06	1.2e-05	1.0e-05	0.000016	0.000023	2.0e-05
1,1,1, trichloroethylene	ESP	1	NA	NA	2.2e-06	NA	NA	0.0000043
methylene chloride	ESP	2	0.00010	0.00039	0.00024	0.00021	0.00078	0.00049
styrene	ESP	2	3.6e-07	1.1e-06	7.5e-07	0.00000072	0.0000022	0.0000015
ethylbenzene	ESP	2	3.6e-07	5.5e-07	4.6e-07	0.00000072	0.0000011	0.0000009
C3 benzenes	ESP	2	2.3e-06	3.6e-07	1.3e-06	0.0000045	0.0000007	0.0000026
C4 benzenes	ESP	2	3.6e-07	5.5e-06	3.0e-06	0.00000072	0.000011	6.0e-06
C6 benzenes	ESP	2	3.6e-07	5.5e-07	4.6e-07	0.00000072	0.0000011	0.0000009
biphenyl	ESP	2	2.2e-06	3.9e-06	3.1e-06	0.0000043	0.0000078	0.0000061
benzaldehyde	ESP	2	2.9e-06	2.2e-05	1.2e-05	0.0000057	0.000043	0.000024
naphthalene	ESP	2	3.6e-06	2.0e-05	1.2e-05	0.0000072	0.00004	0.000024
methylnaphthalene	ESP	2	1.5e-06	2.8e-06	2.1e-06	0.0000029	0.0000056	0.0000042

ESP = electrostatic precipitator.

FF = fabric filter.

TOC = total organic compounds.

ND = no data.

NR = not rated.

NS = not specified.

(a) Cooling tower with multiclone and ESP.

(b) Multiple CEM readings.

TABLE 4-4. SUMMARY OF TEST DATA FOR PORTLAND CEMENT DRY PREHEATER PROCESS KILNS

Pollutant	Type of control	No. of runs	Emission factor, kg/Mg			Emission factor, lb/ton			Data rating	Ref. No.			
			Minimum	Maximum	Average	Minimum	Maximum	Average					
filterable PM	none	4	120	130	125	240	260	250	A	10	11	F/P	0
filterable PM	ESP	4	0.10	0.15	0.13	0.20	0.31	0.26	B	25	1	F	1
filterable PM	FF	2	0.37	0.52	0.45	0.74	1.0	0.89	C	10	2	F/P	1
filterable PM	FF	3	0.085	0.12	0.10	0.17	0.23	0.19	B	52	4	F/P	1
filterable PM	FF	7	0.025	0.10	0.050	0.049	0.19	0.10	C	53	5	F/P	1
filterable PM	FF	3	0.022	0.045	0.031	0.044	0.090	0.063	C	69	6	F	1
filterable PM	FF	2	0.065	0.077	0.071	0.13	0.15	0.14	C	69	7	F	1
filterable PM	FF	3	0.071	0.074	0.072	0.14	0.15	0.14	C	69	8	F	1
filterable PM	FF	9	0.055	0.16	0.11	0.11	0.31	0.22	B	54	9	F/P	1
filterable PM	FF	3	0.13	0.16	0.14	0.25	0.31	0.28	B	55	10	F/P	1
condensible inorg. PM	FF	3	0.010	0.023	0.017	0.020	0.045	0.033	B	55	12	F/P	2
SO2	FF	3	1.0	1.1	1.0	1.9	2.2	2.0	B	52	14	F/P	3
SO2	FF	10	0.0080	0.085	0.042	0.016	0.17	0.083	C	53	15	F/P	3
SO2	FF	8	0.028	0.11	0.055	0.055	0.22	0.11	B	54	17	F/P	3
SO2	FF	3	0.0025	0.0027	0.0026	0.0050	0.0053	0.0052	C	55	18	F/P	3
NOx	FF	9	0.55	3.0	1.2	1.1	6.0	2.4	C	53	21	F/P	4
NOx	FF	9	2.5	3.3	2.9	5.0	6.5	5.8	B	54	23	F/P	4
NOx	FF	3	2.7	3.3	3.1	5.4	6.5	6.2	B	55	24	F/P	4
CO	FF	9	0.26	1.2	0.49	0.52	2.4	0.98	B	54	25	F/P	5
CO2	ESP	4	850	850	850	1,700	1,700	1,700	B	25	26	F	6
CO2	FF	3	850	950	900	1,700	1,900	1,800	B	17	27	F	6
CO2	FF	3	950	1,050	1,000	1,900	2,100	2,000	B	17	28	F	6
CO2	FF	3	1,000	1,000	1,000	2,000	2,000	2,000	B	17	29	F	6
CO2	FF	3	900	900	900	1,800	1,800	1,800	B	52	30	F/P	6
CO2	FF	3	485	950	800	970	1,900	1,600	C	53	31	F/P	6
CO2	FF	2	850	1,100	950	1,700	2,100	1,900	C	69	32	F	6
CO2	FF	3	750	800	800	1,500	1,600	1,600	B	69	33	F	6
CO2	FF	3	600	950	750	1,200	1,900	1,500	B	69	34	F	6

TABLE 4-4. (Continued)

Pollutant	Type of control	No. of runs	Emission factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.			
CO2	FF	9	800	1,000	900	1,600	2,000	1,800	B	54	35	F/P	6
CO2	FF	3	1,100	1,100	1,100	2,100	2,200	2,100	C	55	36	F/P	6
TOC	FF	9	0.070	0.13	0.090	0.14	0.25	0.18	B	54	37		
VOC	FF	9	0.055	0.19	0.13	0.11	0.37	0.25	D	54	37	F/P	7
SO3	FF	3	0.0057	0.017	0.011	0.011	0.034	0.022	B	17	38	F	8
SO3	FF	3	0.0094	0.026	0.016	0.019	0.053	0.032	B	17	39	F	8
SO3	FF	3	0.0054	0.0060	0.0057	0.011	0.012	0.011	B	17	40	F	8
SO3	FF	3	0.0025	0.0064	0.0039	0.0050	0.0128	0.0077	C	55	41	F/P	8
HCl	FF	9	0.010	0.029	0.018	0.019	0.058	0.035	D	54	42	F/P	9

ESP = electrostatic precipator.
FF = fabric filter.
TOC = total organic compounds.
NS = not specified.
NA = not applicable.

TABLE 4-5. SUMMARY OF TEST DATA FOR PORTLAND CEMENT DRY PREHEATER/PRECALCINER KILNS

Pollutant	Type of control	No. runs(a)	ssion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.			
filterable PM	ESP	3	0.017	0.034	0.024	0.034	0.068	0.048	B	31	1	F	1
filterable PM	FF	3a	0.018	0.038	0.026	0.036	0.077	0.053	B	24	2		
filterable PM	FF	3a	0.010	0.017	0.014	0.020	0.034	0.029	B	27	3		
filterable PM	FF	3	0.090	0.13	0.10	0.18	0.25	0.20	C	51			
filterable PM	FF	3b	0.042	0.055	0.050	0.083	0.11	0.099	C	57	4	P	1
filterable PM	FF	3b	0.041	0.050	0.046	0.082	0.10	0.091	C	57	5	P	1
filterable PM	FF	3b	0.025	0.037	0.029	0.049	0.073	0.058	C	57	6	P	1
filterable PM	FF	3b	0.033	0.043	0.039	0.066	0.086	0.077	C	57	7	P	1
filterable PM	FF	2b	0.049	0.060	0.055	0.097	0.12	0.11	C	57	8	P	1
filterable PM	FF	3b	0.023	0.041	0.033	0.046	0.081	0.066	C	57	9	P	1
filterable PM	FF	3b	0.012	0.022	0.018	0.024	0.043	0.036	C	57	10	P	1
filterable PM	FF	3c	0.0094	0.014	0.011	0.019	0.027	0.022	B	61	11	F	1
filterable PM	FF	3c	0.0085	0.034	0.018	0.017	0.067	0.035	B	62	12	F/P	1
filterable PM	FF	3c	0.014	0.018	0.017	0.028	0.036	0.033	B	63	13	F/P	1
filterable PM	FF	6c	0.0028	0.0080	0.0060	0.0055	0.016	0.012	B	64	14	F/P	1
filterable PM	FF	3d	0.12	0.46	0.26	0.24	0.91	0.52	B	56	15	P	1
filterable PM	FF	2d	0.12	0.13	0.13	0.24	0.25	0.25	D	60	16	F/P	1
filterable PM	FF	3	0.11	0.14	0.12	0.21	0.27	0.24	A	76			
condensible inorg. PM	ESP	3	0.13	0.17	0.14	0.26	0.34	0.29	B	31	17	F	2
condensible inorg. PM	FF	3a	0.0020	0.0094	0.0045	0.0039	0.019	0.0090	B	24	18		
condensible inorg. PM	FF	3a	0.0029	0.0076	0.0055	0.0058	0.015	0.011	B	27	19		
condensible inorg. PM	FF	3	0.016	0.035	0.024	0.032	0.070	0.047	B	64	20	F/P	2
condensible inorg. PM	FF	3d	0.12	0.19	0.14	0.23	0.37	0.28	B	56	21	P	2
condensible inorg. PM	FF	2d	0.065	0.070	0.065	0.13	0.14	0.13	D	60	22	F/P	2
SO2	ESP	3	0.29	0.32	0.31	0.58	0.65	0.63	B	31	23	F	3
SO2	ESP	3	1.4	1.5	1.4	2.7	3.1	2.9	B	58	24	F	3
SO2	FF	3a	0.43	0.43	0.43	0.85	0.85	0.85	C	21	25		

TABLE 4-5. (Continued)

Pollutant	Type of control	No. of runs(a)	ssion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.			
SO2	FF	3a	0.53	0.55	0.54	1.1	1.1	1.1	B	24	26		
SO2	FF	3a	0.13	0.14	0.14	0.26	0.27	0.27	B	27	27		
SO2	FF	3	0.50	1.1	0.75	1.0	2.2	1.5	C	51			
SO2	FF	3b	0.24	0.30	0.27	0.47	0.59	0.53	C	57	28	P	3
SO2	FF	3b	0.48	0.50	0.50	0.95	1.0	1.0	C	57	29	P	3
SO2	FF	3b	0.50	0.55	0.50	0.99	1.1	1.0	C	57	30	P	3
SO2	FF	3b	0.12	0.13	0.13	0.24	0.25	0.3	C	57	31	P	3
SO2	FF	3b	0.70	0.75	0.75	1.4	1.5	1.5	C	57	32	P	3
SO2	FF	3b	0.29	0.43	0.35	0.58	0.85	0.70	C	57	33	P	3
SO2	FF	3b	0.36	0.40	0.39	0.72	0.79	0.8	C	57	34	P	3
SO2	FF	6c	0.013	0.045	0.025	0.025	0.090	0.050	B	61	35	F	3
SO2	FF	3c	0.034	0.075	0.055	0.068	0.15	0.11	B	62	36	F/P	3
SO2	FF	3c	0.015	0.019	0.017	0.029	0.037	0.033	B	63	37	F/P	3
SO2	FF	3c	0.020	0.023	0.021	0.039	0.045	0.042	B	64	38	F/P	3
SO2	FF	3d	0.0030	0.0032	0.0031	0.0060	0.0063	0.0061	D	56	39	P	3
SO2	ST	(b)	ND	ND	0.60	ND	ND	1.2	C	59	40	P	3
SO2	ST+ESP	(b)	ND	ND	0.40	ND	ND	0.79	C	59	41	P	3
SO2	NS	NS	NA	NA	0.43	NA	NA	0.85	D	50			
NOx	ESP	3	1.0	1.1	1.1	2.0	2.2	2.2	B	31	42	F	4
NOx	ESP	5	1.8	3.3	2.5	3.5	6.6	5.0	B	49			
NOx	ESP	1	NA	NA	1.6	NA	NA	3.2	NR	65			
NOx	FF	3a	1.4	1.6	1.5	2.9	3.2	3.1	C	21	43		
NOx	FF	3a	1.8	1.9	1.9	3.6	3.7	3.7	B	24	44		
NOx	FF	3a	2.1	2.1	2.1	4.3	4.3	4.3	B	27	45		
NOx	FF	3	1.9	2.0	1.9	3.7	3.9	3.8	C	51			
NOx	FF	3b	1.3	1.5	1.4	2.6	3.0	2.8	C	57	46	P	4
NOx	FF	3b	1.7	1.8	1.7	3.3	3.6	3.4	C	57	47	P	4
NOx	FF	3b	2.0	2.0	2.0	3.9	3.9	3.9	C	57	48	P	4

TABLE 4-5. (Continued)

Pollutant	Type of control	No. of runs(a)	ssion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.			
NOx	FF	3b	1.8	3.0	2.3	3.6	6.0	4.5	C	57	49	P	4
NOx	FF	3b	0.80	0.90	0.85	1.6	1.8	1.7	C	57	50	P	4
NOx	FF	3b	2.7	2.7	2.7	5.3	5.4	5.3	C	57	51	P	4
NOx	FF	3b	2.4	3.2	2.8	4.7	6.3	5.5	C	57	52	P	4
NOx	FF	6c	1.6	2.5	2.1	3.2	5.0	4.1	B	61	53	F	4
NOx	FF	3c	3.4	3.8	3.6	6.8	7.5	7.1	B	62	54	F/P	4
NOx	FF	3c	2.9	3.7	3.3	5.7	7.4	6.5	B	63	55	F/P	4
NOx	FF	3c	3.2	3.4	3.3	6.4	6.7	6.6	B	64	56	F/P	4
NOx	FF	3d	2.0	2.6	2.2	4.0	5.1	4.4	D	56	57	P	4
NOx	FF	2d	4.6	4.9	4.8	9.2	9.7	9.5	C	60	58	F/P	4
NOx	NS	NS	ND	ND	0.17	ND	ND	0.34	D	50			
CO	ESP	3	1.0	1.2	1.1	2.0	2.4	2.2	B	31	59	F	5
CO	ESP	1	NA	NA	0.32	NA	NA	0.63	NR	65			
CO	FF	3a	0.52	0.64	0.58	1.0	1.3	1.2	C	21	60		
CO	FF	3a	0.60	0.65	0.62	1.2	1.3	1.2	B	24	61		
CO	FF	3b	0.24	0.33	0.30	0.48	0.66	0.59	C	57	62	P	5
CO	FF	3b	0.55	1.1	0.85	1.1	2.1	1.7	C	57	63	P	5
CO	FF	3b	0.46	0.60	0.55	0.92	1.2	1.1	C	57	64	P	5
CO	FF	3b	0.26	0.34	0.29	0.51	0.67	0.57	C	57	65	P	5
CO	FF	6c	0.47	1.62	0.85	0.94	3.2	1.7	B	61	66	F	5
CO	FF	3c	0.20	0.38	0.26	0.39	0.76	0.52	B	62	67	F/P	5
CO	FF	3c	1.5	1.8	1.7	3.0	3.5	3.3	B	63	68	F/P	5
CO	FF	3c	2.1	2.7	2.3	4.2	5.3	4.6	C	64	69	F/P	5
CO	FF	3	3.5	5.5	4.4	6.9	11	8.7	A	76			
CO2	ESP	3	800	850	800	1,600	1,700	1,600	B	31	70	F	6
CO2	ESP	1	NA	NA	500	NA	NA	1,000	NR	65			
CO2	FF	3a	900	950	900	1,800	1,900	1,800	C	21	71		
CO2	FF	3a	900	1,000	950	1,800	2,000	1,900	B	24	72		

TABLE 4-5. (Continued)

Pollutant	Type of control	No. of runs(a)	ssion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.			
CO2	FF	3a	950	950	950	1,900	1,900	1,900	B	27	73		
CO2	FF	3c	800	900	850	1,600	1,800	1,700	B	61	74	F	6
CO2	FF	3c	950	1,000	950	1,900	2,000	1,900	B	62	75	F/P	6
CO2	FF	3c	1,000	1,100	1,100	2,000	2,200	2,100	B	63	76	F/P	6
CO2	FF	3c	970	1,000	1,000	1,900	2,000	2,000	B	64	77	F/P	6
CO2	FF	3d	1,050	1,400	1,200	2,100	2,800	2,400	D	56	78	P	6
CO2	FF	12d	1,350	1,400	1,400	2,700	2,800	2,800	C	60	79	F/P	6
CO2	FF	2	700	950	800	1,400	1,900	1,600	D	74			
CO2	FF	6	960	980	970	1,900	2,000	1,900	A	76			
TOC	FF	3a	0.048	0.094	0.064	0.10	0.19	0.13	B	24	80		
TOC	FF	3a	0.032	0.040	0.036	0.065	0.080	0.071	B	27	81		
TOC	FF	3b	0.070	0.075	0.075	0.14	0.15	0.15	C	57	82	P	7
TOC	FF	3b	0.0060	0.014	0.010	0.012	0.027	0.019	C	57	83	P	7
TOC	FF	3b	0.030	0.037	0.033	0.059	0.074	0.066	C	57	84	P	7
TOC	FF	3b	0.044	0.080	0.060	0.088	0.16	0.12	C	57	85	P	7
TOC	FF	3b	0.035	0.060	0.045	0.069	0.12	0.090	C	57	86	P	7
TOC	FF	3b	0.017	0.025	0.020	0.033	0.050	0.040	C	57	87	P	7
TOC	FF	3	0.036	0.085	0.054	0.071	0.17	0.11	B	61	88	F	7
TOC	FF	3	0.16	0.20	0.18	0.31	0.39	0.35	A	76			
sulfate	FF	3a	0.0066	0.0069	0.0068	0.013	0.014	0.014	B	24	89		
sulfate	FF	3a	1.2E-006	2.0E-006	1.7E-006	0.00000238	0.0000039	3.4E-006	B	27	90		
sulfate	FF	3b	0.0017	0.0031	0.0026	0.0033	0.0062	0.0052	C	57	91	P	8
sulfate	FF	3b	0.0030	0.0055	0.0044	0.0059	0.011	0.0087	C	57	92	P	8
sulfate	FF	3b	0.0040	0.0055	0.0047	0.0080	0.011	0.0094	C	57	93	P	8
sulfate	FF	3b	0.0008	0.0022	0.0014	0.0016	0.0043	0.0027	C	57	94	P	8
sulfate	FF	3b	0.0060	0.0065	0.0065	0.012	0.013	0.013	C	57	95	P	8
sulfate	FF	3b	0.0023	0.0031	0.0026	0.0045	0.0062	0.0051	C	57	96	P	8

TABLE 4-5. (Continued)

Pollutant	Type of control	No. of runs(a)	ssion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.				
SO3	FF	3	0.0020	0.0069	0.0053	0.0041	0.0138	0.0105	B	24	97			
HCl	FF	3	0.13	0.14	0.14	0.26	0.29	0.27	B	64	98	F/P	9	
HCl	FF	3	0.00094	0.0016	0.0013	0.0019	0.0032	0.0026	D	74				
HCl	FF	3	0.0024	0.0095	0.0060	0.0048	0.019	0.012	A	76				
Cl	FF	3	6.5E-004	1.5E-003	1.1E-003	0.0013	0.0029	0.0021	A	76				
NH3	FF	3	0.0050	0.0052	0.0051	0.010	0.010	0.010	D	64	99	F/P	10	
Ag	FF	3	3.0E-007	3.2E-007	3.1E-007	5.9E-007	6.3E-007	6.1E-007	A	76				
As	FF	3	5.0E-006	7.0E-006	6.0E-006	1.0E-005	1.4E-005	1.2E-005	A	76				
Ba	FF	3	0.00011	0.00049	0.00023	0.00021	0.00098	0.00046	A	76				
Be	FF	3	1.9E-007	5.0E-007	3.3E-007	3.8E-007	9.9E-007	6.6E-007	A	76				
Cd	FF	3	3.7E-006	1.5E-005	7.9E-006	7.3E-006	3.1E-005	1.6E-005	D	74				
Cd	FF	3	9.5E-007	1.3E-006	1.1E-006	0.0000019	0.0000025	0.0000022	A	76				
Cr	FF	3	4.8E-005	0.00011	7.0E-005	0.000096	0.00022	0.00014	A	76				
Cu	FF	3	0.00011	0.0077	0.0026	0.00022	0.015	0.0053	D	74				{EDIT}*1.7~
Hg	FF	3	8.5E-005	0.00014	0.00010	0.00017	0.00027	0.00020	D	74				
Hg	FF	3	9.0E-006	1.3E-005	1.0E-005	1.8E-005	2.5E-005	2.0E-005	A	76				
Pb	FF	3	1.4E-005	6.3E-005	3.4E-005	2.9E-005	0.00013	6.8E-005	D	74				
Pb	FF	3	3.5E-005	4.0E-005	3.8E-005	0.000069	8.0E-005	0.000075	A	76				
Se	FF	3	8.5E-005	0.00013	0.00010	0.00017	0.00026	0.00020	D	74				
Th	FF	3	2.3E-006	3.5E-006	2.7E-006	0.0000046	0.0000069	0.0000054	A	76				
Zn	FF	3	0.00020	0.00039	0.00028	0.00041	0.00078	0.00056	D	74				
Zn	FF	3	0.00010	0.00029	0.00017	0.00020	0.00058	0.00034	A	76				
acenaphthalene	FF	3	5.3E-006	0.00015	5.9E-005	1.1E-005	0.00031	0.00012	D	74				
acenaphthene	FF	1	NA	NA	1.0E-005	NA	NA	2.0E-005	NR	74				
acetone	ESP	1	NA	NA	2.5E-005	NA	NA	4.9E-005	NR	65				
anthracene	FF	1	NA	NA	6.5E-006	NA	NA	1.3E-005	NR	74				
benzene	FF	3	0.0057	0.0094	0.0080	0.011	0.019	0.016	D	74				

TABLE 4-5. (Continued)

Pollutant	Type of control	No. of runs(a)	ssion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.
benzene	ESP	1	NA	NA	0.00043	NA	NA	0.00086	NR	65
benzo(a)anthracene	FF	3	2.0E-008	2.5E-008	2.1E-008	3.9E-008	4.9E-008	4.3E-008	D	74
benzo(a)pyrene	FF	3	4.9E-008	8.5E-008	6.5E-008	9.9E-008	1.7E-007	1.3E-007	D	74
benzo(b)fluoranthene	FF	3	6.5E-008	6.6E-007	2.8E-007	1.3E-007	1.3E-006	5.6E-007	D	74
benzo(g,h,i)perylene	FF	3	2.5E-008	4.7E-008	3.9E-008	4.9E-008	9.4E-008	7.8E-008	D	74
benzo(k)fluoranthene	FF	3	6.3E-008	9.4E-008	7.7E-008	1.3E-007	1.9E-007	1.5E-007	D	74
bis(2-ethylhexyl)phthalate	ESP	1	NA	NA	0.00011	NA	NA	0.00021	NR	65
chrysene	FF	3	5.4E-008	1.0E-007	8.1E-008	1.1E-007	2.0E-007	1.6E-007	D	74
dibens(a,h)anthracene	FF	3	2.4E-008	3.9E-008	3.1E-007	4.8E-008	7.8E-008	6.3E-007	D	74
1,1-dichloroethene	ESP	1	NA	NA	8.0E-007	NA	NA	1.6E-006	NR	65
ethylbenzene	ESP	1	NA	NA	6.5E-005	NA	NA	0.00013	NR	65
fluoranthene	FF	3	1.7E-006	6.5E-006	4.4E-006	3.4E-006	1.3E-005	8.8E-006	D	74
fluorene	FF	3	1.1E-006	1.7E-005	9.4E-006	2.2E-006	3.4E-005	1.9E-005	D	74
formaldehyde	FF	3	0.00022	0.00027	0.00023	0.00044	0.00054	0.00046	D	74
indeno(1,2,3-cd)pyrene	FF	3	2.4E-008	6.3E-008	4.3E-008	4.8E-008	1.3E-007	8.7E-008	D	74
methylene chloride	ESP	1	NA	NA	0.00023	NA	NA	0.00046	NR	65
monochlorobenzene	ESP	1	NA	NA	4.7E-006	NA	NA	9.4E-006	NR	65
naphthalene	FF	3	8.2E-005	0.0020	0.00085	0.00016	0.0039	0.0017	D	74
phenanthrene	FF	3	2.8E-005	0.00044	0.00020	5.6E-005	0.00088	0.00039	D	74
pyrene	FF	3	7.7E-007	3.5E-006	2.2E-006	1.5E-006	7.0E-006	4.4E-006	D	74
tetrachloroethene	ESP	1	NA	NA	2.2E-006	NA	NA	4.3E-006	NR	65
toluene	ESP	1	NA	NA	0.00041	NA	NA	0.00082	NR	65
trichloroethene	ESP	1	NA	NA	2.6E-006	NA	NA	5.2E-006	NR	65
trichlorofluoromethane	ESP	1	NA	NA	3.3E-005	NA	NA	6.5E-005	NR	65
1,1,1-trichloroethane	ESP	1	NA	NA	4.0E-007	NA	NA	8.0E-007	NR	65
total HpCDD	FF	3	1.8E-010	2.1E-010	2.0E-010	3.6E-010	4.3E-010	3.9E-010	D	74
total OCDD	FF	3	8.5E-010	1.3E-009	1.0E-009	1.7E-009	2.6E-009	2.0E-009	D	74

TABLE 4-5. (Continued)

Pollutant	Type of control	No. of runs(a)	ssion factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.
total PCDD	FF	3	1.2E-009	1.5E-009	1.4E-009	2.4E-009	3.1E-009	2.7E-009	D	74
total PCDF	FF	2	1.1E-010	1.9E-010	1.4E-010	2.2E-010	3.7E-010	2.9E-010	D	74
total TCDF	FF	2	1.1E-010	1.9E-010	1.4E-010	2.2E-010	3.7E-010	2.9E-010	D	74
CDD/CDF	ESP	1	NA	NA	1.2E-009	NA	NA	2.3E-009	NR	65
1,2,3,4,6,7,8 HpCDD	FF	3	1.1E-010	1.1E-010	1.1E-010	2.2E-010	2.2E-010	2.2E-010	D	74

ESP = electrostatic precipitator.
FF = fabric filter.
ST = spray tower.
TOC = total organic compounds.
NA = not applicable.
NR = not rated.
(a) Multiple tests on same kiln indicated by a-d.
(b) Average CEM readings over 3-day period.

TABLE 4-6. SUMMARY OF TEST DATA FOR PORTLAND CEMENT CLINKER COOLERS

	Type of	No. of	Emission factor, kg/Mg			Emission factor, lb/ton		
Pollutant	control	runs(a)	Minimum	Maximum	Average	Minimum	Maximum	Average
filterable PM	ESP	3	0.040	0.055	0.048	0.08	0.11	0.096
filterable PM	FF	3	0.20	0.27	0.24	0.41	0.54	0.47
filterable PM	FF	3	0.012	0.022	0.017	0.025	0.045	0.034
filterable PM	FF	3	0.0036	0.010	0.0060	0.0071	0.020	0.012
filterable PM	FF	3a	0.0032	0.0044	0.0036	0.0064	0.0087	0.0072
filterable PM	FF	3a	0.010	0.010	0.010	0.020	0.020	0.020
filterable PM	GBF	3	0.075	0.090	0.080	0.15	0.18	0.16
filterable PM	GBF	3	0.032	0.070	0.055	0.064	0.14	0.11
filterable PM	C/GFB	2	0.060	0.085	0.070	0.12	0.17	0.14
filterable PM	C/GFB	3	0.16	0.24	0.18	0.32	0.48	0.35
condensible inorg. PM	ESP	3	0.0026	0.0044	0.0038	0.0052	0.0088	0.0075
condensible inorg. PM	FF	3	0.0050	0.014	0.0090	0.010	0.027	0.018
condensible inorg. PM	FF	3	0.010	0.020	0.016	0.021	0.04	0.031
condensible inorg. PM	FF	3	0.0000	0.0010	0.00034	0.0000	0.0020	0.00067
condensible inorg. PM	GBF	3	0.0024	0.0070	0.0050	0.0048	0.014	0.010
condensible inorg. PM	GBF	3	0.0027	0.0060	0.0040	0.0054	0.012	0.0079
Be	ESP	1	NA	NA	4.0e-07	NA	NA	8.0e-07
Be	FF	1	NA	NA	0.0000004	NA	NA	8.7e-07
Cd	FF	1	NA	NA	0.0000085	NA	NA	1.7e-05

TABLE 4-6. (Continued)

Cr	ESP	1	NA	NA	7.5e-05	NA	NA	0.00015
Cr	FF	1	NA	NA	0.00018	NA	NA	0.00037
Cu	ESP	1	NA	NA	1.3e-05	NA	NA	2.6e-05
Cu	FF	1	NA	NA	0.00011	NA	NA	0.00022
Fe	ESP	1	NA	NA	0.0014	NA	NA	0.0027
Fe	FF	1	NA	NA	0.0070	NA	NA	0.014
Mn	ESP	1	NA	NA	1.7e-05	NA	NA	3.4e-05
Mn	FF	1	NA	NA	8.5e-05	NA	NA	0.00017

TABLE 4-6. (Continued)

Pollutant	Type of control	No. runs(a)	Emission factor, kg/Mg			Emission factor, lb/ton		
			Minimum	Maximum	Average	Minimum	Maximum	Average
Ni	ESP	1	NA	NA	7.5e-05	NA	NA	0.00015
Ni	FF	1	NA	NA	0.00011	NA	NA	0.00022
Pb	FF	1	NA	NA	6.5e-05	NA	NA	0.00013
Sb	FF	1	NA	NA	0.0000215	NA	NA	4.3e-05
Sr	ESP	1	NA	NA	0.00022	NA	NA	0.00043
Sr	FF	1	NA	NA	0.00044	NA	NA	0.00087
V	ESP	1	NA	NA	1.1e-05	NA	NA	2.2e-05
Zn	FF	1	NA	NA	0.00085	NA	NA	0.0017

ESP = electrostatic precipitator.

FF = fabric filter.

C = cylcone.

GBF = gravel bed filter.

NA = not applicable.

NR = not rated.

(a) Multiple tests on same clinker cooler indicated by a.

TABLE 4-7. SUMMARY OF TEST DATA FOR PORTLAND CEMENT OTHER PROCESSES

Pollutant	Type of control	No. of runs	Emission factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.	pollutant	apcd	POLLUTAN	APCD
RAW MILL														
filterable PM	FF	2	0.0080	0.0090	0.0085	0.016	0.018	0.017	C	8	F	1		
filterable PM	FF	3	0.0041	0.0048	0.0045	0.0081	0.0096	0.0089	B	61				
filterable PM	FF	3	0.0043	0.0060	0.0055	0.0086	0.012	0.011	B	62				
Sb	FF	1	NA	NA	9.5E-007	NA	NA	0.0000019	NR	8	F			
Cr	FF	1	NA	NA	9.5E-007	NA	NA	0.0000019	NR	8	F			
Cu	FF	1	NA	NA	4.7E-006	NA	NA	0.0000094	NR	8	F			
Fe	FF	1	NA	NA	4.7E-005	NA	NA	0.000094	NR	8	F			
Mn	FF	1	NA	NA	3.8E-006	NA	NA	0.0000075	NR	8	F			
Sr	FF	1	NA	NA	1.9E-005	NA	NA	0.000038	NR	8	F			
Zn	FF	1	NA	NA	1.9E-006	NA	NA	0.0000038	NR	8	F			
RAW MILL FEED BELT														
filterable PM	FF	2	0.0012	0.0020	0.0016	0.0023	0.0039	0.0031	C	62				
RAW MILL WEIGH HOPPER														
filterable PM	FF	2	0.0075	0.012	0.010	0.015	0.023	0.019	C	8	F			
Be	FF	1	NA	NA	1.3E-008	NA	NA	2.5E-008	NR	8	F			
Cr	FF	1	NA	NA	3.8E-006	NA	NA	0.0000076	NR	8	F			
Cu	FF	1	NA	NA	3.8E-006	NA	NA	0.0000076	NR	8	F			
Fe	FF	1	NA	NA	1.3E-005	NA	NA	0.000025	NR	8	F			
Pb	FF	1	NA	NA	2.6E-006	NA	NA	0.0000051	NR	8	F			
Mn	FF	1	NA	NA	6.5E-006	NA	NA	0.000013	NR	8	F			
Ni	FF	1	NA	NA	5.0E-006	NA	NA	1.0E-005	NR	8	F			
Zn	FF	1	NA	NA	2.6E-006	NA	NA	0.0000051	NR	8	F			
RAW MILL AIR SEPARATOR														
filterable PM	FF	2	0.014	0.019	0.016	0.027	0.038	0.032	C	8	F			
Cd	FF	1	NA	NA	4.5E-007	NA	NA	8.9E-007	NR	8	F			
Cu	FF	1	NA	NA	7.5E-006	NA	NA	1.5E-005	NR	8	F			
Fe	FF	1	NA	NA	2.1E-005	NA	NA	4.1E-005	NR	8	F			

TABLE 4-7. (Continued)

Pollutant	Type of control	No. runs	Emission factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.	pollutant	apcd	POLLUTAN	APCD
Pb	FF	1	NA	NA	1.5E-006	NA	NA	3.0E-006	NR	8	F			
Mn	FF	1	NA	NA	7.5E-006	NA	NA	1.5E-005	NR	8	F			
Zn	FF	1	NA	NA	9.0E-006	NA	NA	1.8E-005	NR	8	F			
FINISH GRINDING MILL														
filterable PM	FF	3	0.0065	0.0070	0.0065	0.013	0.014	0.013	B	3	F	1		
filterable PM	FF	3	0.0060	0.010	0.0080	0.012	0.020	0.016	B	5	F	1		
filterable PM	FF	2	0.0030	0.0030	0.0030	0.0060	0.0060	0.0060	C	8	F	1		
filterable PM	FF	3	0.00044	0.0021	0.0015	0.00088	0.0041	0.0029	B	61				
filterable PM	FF	3	0.00110	0.0033	0.0020	0.0022	0.0065	0.0040	B	62				
FINISH GRINDING MILL FEED BELT														
filterable PM	FF	3	0.0012	0.0014	0.0012	0.0023	0.0027	0.0024	B	62				
FINISH GRINDING MILL WEIGH HOPPER														
filterable PM	FF	3	0.0046	0.0048	0.0047	0.0092	0.0095	0.0094	C	8	F			
Cd	FF	1	NA	NA	7.5E-007	NA	NA	0.0000015	NR	8	F			
Cr	FF	1	NA	NA	2.3E-006	NA	NA	0.0000045	NR	8	F			
Cu	FF	1	NA	NA	5.5E-006	NA	NA	0.000011	NR	8	F			
Fe	FF	1	NA	NA	1.8E-004	NA	NA	0.00036	NR	8	F			
Mn	FF	1	NA	NA	3.8E-006	NA	NA	0.0000076	NR	8	F			
Ni	FF	1	NA	NA	6.0E-006	NA	NA	0.000012	NR	8	F			
Zn	FF	1	NA	NA	3.1E-005	NA	NA	0.000061	NR	8	F			
FINISH GRINDING MILL AIR SEPARATOR														
filterable PM	FF	3	0.018	0.021	0.020	0.035	0.042	0.039	B	3	F	1		
filterable PM	FF	2	0.0080	0.0085	0.0085	0.016	0.017	0.017	C	8	F	1		
Cd	FF	1	NA	NA	1.3E-006	NA	NA	0.0000026	NR	8	F			
Cu	FF	1	NA	NA	1.6E-005	NA	NA	0.000032	NR	8	F			
Fe	FF	1	NA	NA	1.3E-004	NA	NA	0.00026	NR	8	F			
Mn	FF	1	NA	NA	4.9E-006	NA	NA	0.0000097	NR	8	F			
Ni	FF	1	NA	NA	1.6E-006	NA	NA	0.0000032	NR	8	F			
Zn	FF	1	NA	NA	6.5E-005	NA	NA	0.00013	NR	8				

TABLE 4-7. (Continued)

Pollutant	Type of control	No. runs	Emission factor, kg/Mg Minimum	Maximum	Average	Emission factor, lb/ton Minimum	Maximum	Average	Data rating	Ref. No.	pollutant	apcd	POLLUTAN	APCD
PRIMARY LIMESTONE CRUSHING														
filterable PM	FF	4	0.00040	0.00070	0.00050	0.00079	0.0014	0.0010	B	9	F			
PRIMARY LIMESTONE SCREENING														
filterable PM	FF	4	9.0E-005	0.00013	0.00011	0.00018	0.00026	0.00022	C	9	F			
LIMESTONE TRANSFER														
filterable PM	FF	3	8.5E-006	2.1E-005	1.5E-005	1.7E-005	4.1E-005	2.9E-005	B	9	F			
SECONDARY LIMESTONE SCREENING AND CRUSHING														
filterable PM	FF	3	8.5E-005	0.00021	0.00016	0.00017	0.00041	0.00031	B	9	F	1		

FF = fabric filter.
NA = not applicable.
NR = not rated.

TABLE 4-8. SUMMARY OF AVERAGE PARTICLE SIZE DISTRIBUTION FOR PORTLAND CEMENT KILNS[a]

Particle size, µm	Cumulative mass percent equal to or less than stated size			
	Uncontrolled		Controlled	
	Wet process	Dry process	Wet process with ESP	Dry process with FF
2.5	7	18	64	45
5.0	20	ND	83	77
10.0	24	42	85	84
15.0	35	44	91	89
20.0	57	ND	98	100

[a]Reference 79.

TABLE 4-9. SUMMARY OF AVERAGE PARTICLE SIZE DISTRIBUTION FOR PORTLAND CEMENT CLINKER COOLERS[a]

Particle size, µm	Cumulative mass percent equal to or less than stated size	
	Uncontrolled	With gravel bed filter
2.5	0.54	40
5.0	1.5	64
10.0	8.6	76
15.0	21	84
20.0	34	89

[a]Reference 79.

TABLE 4-10. ESTIMATED CO_2 EMISSION FACTORS FOR PORTLAND CEMENT KILNS[a]

Kiln process	Fuel requirements, j/Mg (MMBtu/ton)	CO_2 emission factor			
		Fuel combustion,		for $CaCO_3$,	Total,
		kg/j (lb/MMBtu)	kg/Mg (lb/ton)	kg/Mg (lb/ton)	kg/Mg (lb/ton)
Coal-fired					
Wet	6.00×10^9 (5.14)	0.100×10^{-6} (233)	600 (1,200)	500 (1,000)	1,100 (2,200)
Dry	5.59×10^9 (4.82)	0.100×10^{-6} (233)	560 (1,100)	500 (1,000)	1,100 (2,100)
Preheater	4.24×10^9 (3.65)	0.100×10^{-6} (233)	430 (850)	500 (1,000)	930 (1,900)
Gas-fired					
Wet	6.00×10^9 (5.14)	0.603×10^{-6} (140)	360 (720)	500 (1,000)	860 (1,700)
Dry	5.59×10^9 (4.82)	0.603×10^{-6} (140)	340 (680)	500 (1,000)	840 (1,700)
Preheater	4.24×10^9 (3.65)	0.603×10^{-6} (140)	260 (510)	500 (1,000)	760 (1,500)

[a]Reference 80.

TABLE 4-11. SUMMARY OF CRITERIA POLLUTANT EMISSION FACTORS FOR WET PROCESS KILNS

Pollutant	Type of control	No. of tests	No. of kilns	Average emission factor kg/Mg	lb/ton	Factor rating	References
filterable PM	none	2	2	65	130	D	13,19
filterable PM	ESP	20	11	0.38	0.77	C	1,2,11,13,18,19,26,28, 29,30,40,42,43,44,67,77
filterable PM	FF	1	1	0.23	0.46	E	7
filterable PM	CT/MC/ESP	1	1	0.10	0.20	E	14
condensible inorg. PM	ESP	4	4	0.076	0.15	D	1,2,13,77
condensible inorg. PM	FF	1	1	0.10	0.20	E	7
condensible inorg. PM	CT/MC/ESP	1	1	0.14	0.29	E	14
filterable PM-10	none	(a)	1	16	31	D	19,79
filterable PM-10	ESP	(b)	2	0.33	0.65	D	1,2,11,13,18,19,26,28,29, 30,40,42,43,44,67,77,79
SO2	none	17	8	4.1	8.2	C	13,18,19,26,28,29,30, 40,42,44,77
NOx	none	7	6	3.7	7.4	D	19,28,29,30,43,77
CO	none	1	1	0.060	0.12	D	77
CO2	none	12	7	1,100	2,100	C	18,19,26,28,29,30,44, 67,77
TOC	none	1	1	0.014	0.028	D	77

ESP = electrostatic precipitator.
FF = fabric filter.
CT = cooling tower.
MC = multiclone.
TOC = total organic compounds.
(a) Based on a single particle size test.
(b) Based on two particle size tests.

TABLE 4-12. SUMMARY OF CRITERIA POLLUTANT EMISSION FACTORS FOR LONG DRY PROCESS KILNS

Pollutant	Type of control	No. of tests	Average emission factor kg/Mg	Average emission factor lb/ton	Factor rating	References
filterable PM	ESP	5	0.50	1.00	D	12,14
filterable PM	FF	1	0.10	0.20	D	16
condensible inorg. PM	ESP	5	0.19	0.38	D	12,14
condensible inorg. PM	FF	1	0.45	0.89	D	16
filterable PM-10	FF	(a)	0.084	0.17	D	16,79
SO2	none	5	4.9	10	D	4,12,36,37
NOx	none	7	3.0	6.0	D	4,35,36,37,78
CO	none	2	0.11	0.21	E	36,78
CO2	none	6	900	1,800	D	4,14,16,78
TOC	none	2	0.014	0.028	E	37,78

ESP = electrostatic precipitator.
FF = fabric filter.
CT = cooling tower.
MC = multiclone.
TOC = total organic compounds.
(a) Based on two particle size tests.

TABLE 4-13. SUMMARY OF CRITERIA POLLUTANT EMISSION FACTORS FOR PREHEATER PROCESS KILNS

Pollutant	Type of control	No. of tests	Average emission factors kg/Mg	lb/ton	Factor rating	References
filterable PM	none	1	130	250	D	10
filterable PM	ESP	1	0.13	0.26	D	25
filterable PM	FF	8	0.13	0.25	C	10,52,53,54,55,69
condensible inorg. PM	FF	1	0.017	0.033	D	55
SO2	none	4	0.27	0.55	D	52,53,54,55
NOx	none	3	2.4	4.8	D	53,54,55
CO	none	1	0.49	0.98	D	54
CO2	none	11	900	1,800	C	17,25,52,53,54,55,69
TOC	none	1	0.090	0.18	D	54

ESP = electrostatic precipator.
FF = fabric filter.
TOC = total organic compounds.

TABLE 4-14. SUMMARY OF CRITERIA POLLUTANT EMISSION FACTORS FOR PREHEATER/PRECALCINER KILNS

Pollutant	Type of control	No. of tests	No. of kilns	Average emission factors kg/Mg	lb/ton	Factor rating	References
filterable PM	ESP	1	1	0.024	0.048	D	31
filterable PM	FF	8	4	0.10	0.21	D	24,27,56,61,62,63,64,76
condensible inorg. PM	controlled	5	4	0.078	0.16	D	24,27,31,56,64
SO2	none	9	4	0.54	1.1	D	21,24,27,31,58,61,62, 63,64
SO2	ST	2	2	0.50	1.0	E	59
NOx	none	9	4	2.1	4.2	D	21,24,27,31,49,61,62, 63,64
CO	none	7	4	1.8	3.7	D	21,24,31,61,62,63,76
CO2	none	11	11	900	1,800	E	17,25,52,53,54,55,69
TOC	none	4	2	0.059	0.12	D	24,27,61,76

ESP = electrostatic precipator.
FF = fabric filter.
ST = spray tower.
TOC = total organic compounds.

TABLE 4-15. SUMMARY OF NONCRITERIA POLLUTANT EMISSION FACTORS FOR PORTLAND CEMENT KILNS

Pollutant	Type of control	No. of tests	No. of kilns	Average emission factor kg/Mg	lb/ton	Factor rating	References
Ag	FF	1	1	3.1E-007	6.1E-007	D	76
Al	ESP	1	1	0.0065	0.013	E	78
As	ESP	1	1	6.5E-006	0.000013	E	78
As	FF	1	1	6.0E-006	1.2E-005	D	76
Ba	ESP	1	1	0.00018	0.00035	D	77
Ba	FF	1	1	0.00023	0.00046	D	76
Be	FF	1	1	3.3E-007	6.6E-007	D	76
Ca	ESP	1	1	0.12	0.24	E	78
Cd	ESP	1	1	4.2E-006	0.0000083	D	77
Cd	FF	1	1	1.1E-006	0.0000022	D	76
Cl	ESP	6	2	0.34	0.68	E	18,42,43,44
Cl	FF	1	1	0.0011	0.0021	D	76
Cr	ESP	1	1	3.9E-006	0.0000077	E	77
Cr	FF	1	1	7.0E-005	0.00014	D	76
Cu	FF	1	1	0.0026	0.0053	E	74
F	ESP	1	1	0.00045	0.00090	E	43
Fe	ESP	1	1	0.0085	0.017	E	78
HCl	ESP	2	2	0.025	0.049	E	40,78
HCl	FF	2	2	0.073	0.14	D	64,76
Hg	ESP	1	1	0.00011	0.00022	D	77
Hg	FF	2	2	1.2E-005	2.4E-005	D	4,76
K	ESP	5	2	0.0090	0.018	D	18,42,43
Mn	ESP	1	1	0.00043	0.00086	E	78
NH3	FF	1	1	0.0051	0.010	E	64
NH4	ESP	6	2	0.054	0.11	D	18,42,43,44
NO3	ESP	1	1	0.0023	0.0046	E	43
Na	ESP	6	2	0.020	0.038	D	18,42,43,44
Pb	ESP	1	1	0.00036	0.00071	D	77
Pb	FF	1	1	3.8E-005	0.000075	D	76

TABLE 4-15. (Continued)

Pollutant	Type of control	No. of tests	No. of kilns	Average emission factor kg/Mg	Average emission factor lb/ton	Factor rating	References
SO3	ESP	2	2	0.042	0.086	E	18
SO3	FF	5	2	0.0073	0.014	D	17,24,55
SO4	ESP	6	2	0.10	0.20	D	18,42,43,44
SO4	FF	8	2	0.0036	0.0072	D	24,27,57
Se	ESP	1	1	7.5E-005	0.00015	E	78
Se	FF	1	1	0.00010	0.00020	E	74
Th	FF	1	1	2.7E-006	0.0000054	D	76
Ti	ESP	1	1	0.00019	0.00037	E	78
Zn	ESP	1	1	0.00027	0.00054	D	77
Zn	FF	1	1	0.00017	0.00034	D	76
1,2,3,4,6,7,8 HpCDD	FF	1	1	1.1E-010	2.2E-010	E	74
C3 benzenes	ESP	1	1	1.3E-006	0.0000026	E	78
C4 benzenes	ESP	1	1	3.0E-006	6.0E-006	E	78
C6 benzenes	ESP	1	1	4.6E-007	0.00000092	E	78
acenaphthalene	FF	1	1	5.9E-005	0.00012	E	74
acetone	ESP	1	1	0.00019	0.00037	D	77
benzaldehyde	ESP	1	1	1.2E-005	0.000024	E	78
benzene	ESP	1	1	0.0016	0.0031	D	77
benzene	FF	1	1	0.0080	0.016	E	74
benzo(a)anthracene	FF	1	1	2.1E-008	4.3E-008	E	74
benzo(a)pyrene	FF	1	1	6.5E-008	1.3E-007	E	74
benzo(b)fluoranthene	FF	1	1	2.8E-007	5.6E-007	E	74
benzo(g,h,i)perylene	FF	1	1	3.9E-008	7.8E-008	E	74
benzo(k)fluoranthene	FF	1	1	7.7E-008	1.5E-007	E	74
benzoic acid	ESP	1	1	0.0018	0.0035	D	77
biphenyl	ESP	1	1	3.1E-006	0.0000061	E	78
bis(2-ethylhexyl)phthalate	ESP	1	1	4.8E-005	0.000095	D	77
bromomethane	ESP	1	1	2.2E-005	0.000043	E	77
carbon disulfide	ESP	1	1	5.5E-005	0.00011	D	77

TABLE 4-15. (Continued)

Pollutant	Type of control	No. of tests	No. of kilns	Average emission factor kg/Mg	Average emission factor lb/ton	Factor rating	References
chlorobenzene	ESP	1	1	8.0E-006	0.000016	D	77
chloromethane	ESP	1	1	0.00019	0.00038	E	77
chrysene	FF	1	1	8.1E-008	1.6E-007	E	74
di-n-butylphthalate	ESP	1	1	2.1E-005	0.000041	D	77
dibenz(a,h)anthracene	FF	1	1	3.1E-007	6.3E-007	E	74
ethylbenzene	ESP	1	1	9.5E-006	0.000019	D	77
fluoranthene	FF	1	1	4.4E-006	8.8E-006	E	74
fluorene	FF	1	1	9.4E-006	1.9E-005	E	74
formaldehyde	FF	1	1	0.00023	0.00046	E	74
freon 113	ESP	1	1	2.5E-005	5.0E-005	E	78
indeno(1,2,3-cd)pyrene	FF	1	1	4.3E-008	8.7E-008	E	74
methyl ethyl ketone	ESP	1	1	1.5E-005	3.0E-005	E	77,78
methylene chloride	ESP	1	1	0.00025	0.00049	E	78
methylnaphthalene	ESP	1	1	2.1E-006	0.0000042	E	78
naphthalene	FF	1	1	0.00085	0.0017	E	74
naphthalene	ESP	1	1	0.00011	0.00022	D	77
phenanthrene	FF	1	1	0.00020	0.00039	E	74
phenol	ESP	1	1	5.5E-005	0.00011	D	77
pyrene	FF	1	1	2.2E-006	4.4E-006	E	74
styrene	ESP	1	1	7.5E-007	0.0000015	E	78
toluene	ESP	1	1	0.00010	0.00019	D	77
total HpCDD	FF	1	1	2.0E-010	3.9E-010	E	74
total OCDD	FF	1	1	1.0E-009	2.0E-009	E	74
total PCDD	FF	1	1	1.4E-009	2.7E-009	E	74
total PCDF	FF	1	1	1.4E-010	2.9E-010	E	74
total TCDF	FF	1	1	1.4E-010	2.9E-010	E	74
xylenes	ESP	1	1	6.5E-005	0.00013	D	77

ESP = electrostatic precipitator.
FF = fabric filter.

TABLE 4-16. SUMMARY OF AVERAGE EMISSION FACTORS FOR CLINKER COOLERS

Pollutant	Type of control	No. of tests	Average emission factors kg/Mg	lb/ton	Factor rating	References	
filterable PM	ESP	1	0.048	0.096	D		1
filterable PM	FF	5	0.068	0.13	D	2,5,20,24,27	
filterable PM	GBF	3	0.11	0.21	D	15,23,25	
condensible inorg. PM	ESP	1	0.0038	0.0075	D		1
condensible inorg. PM	FF	3	0.0084	0.017	D	2,5,24	
condensible inorg. PM	GBF	2	0.0045	0.090	D	15,23	
filterable PM-10	GBF	1	0.084	0.16	D	15,23,25,79	

ESP = electrostatic precipitator.
FF = fabric filter.
GBF = gravel bed filter.

TABLE 4-17. SUMMARY OF AVERAGE EMISSION FACTORS FOR OTHER PROCESSES							
	Type of	No. of	Average emission factor,		Factor		
Pollutant	control	tests	kg/Mg	lb/ton	rating	Refs.	
RAW MILL							
filterable PM	FF	3	0.0062	0.012	D	8,61,62	
RAW MILL FEED BELT							
filterable PM	FF	1	0.0016	0.0031	E	62	
RAW MILL WEIGH HOPPER							
filterable PM	FF	1	0.010	0.019	E	8	
RAW MILL AIR SEPARATOR							
filterable PM	FF	1	0.016	0.032	E	8	
FINISH GRINDING MILL							
filterable PM	FF	5	0.0042	0.0080	D	3,5,8,61,62	
FINISH GRINDING MILL FEED BELT							
filterable PM	FF	1	0.0012	0.0024	E	62	
FINISH GRINDING MILL WEIGH HOPPER							
filterable PM	FF	1	0.0047	0.0094	E	8	
FINISH GRINDING MILL AIR SEPARATOR							
filterable PM	FF	2	0.014	0.028	D	38	
PRIMARY LIMESTONE CRUSHING							
filterable PM	FF	1	0.00050	0.0010	E	9	
PRIMARY LIMESTONE SCREENING							
filterable PM	FF	1	0.00011	0.00022	E	9	
LIMESTONE TRANSFER							
filterable PM	FF	1	1.5e-05	2.9e-05	E	9	
SECONDARY LIMESTONE SCREENING AND CRUSHING							
filterable PM	FF	1	0.00016	0.00031	E	9	
FF = fabric filter.							
NA = not applicable.							
NR = not rated.							

In addition to the tables for this chapter is a Lotus 1,2,3 spreadsheet file (Cementr6.wk4) that contains summary statistical information about emission factors presented in the AP-42 section and background report. This information is not contained in the background report or the final AP-42 section and can be used for uncertainty estimates. To obtain this file, download it from http://www.epa.gov/ttn/chief/fbgdocs/b11s06.zip Unzip the file and open Cementr6.wk4

4.2.1.2 Reference 2. This report documents measurements of filterable PM, condensible inorganic PM, and CO_2 emissions from a gas-fired rotary kiln and a clinker cooler. A trace metal analysis was also conducted on the total PM catches for one run of the kiln and cooler tests. The emission test was conducted in 1971 and was sponsored by EPA as part of the development of an NSPS for portland cement plants. The plant uses the wet process, and process rates were provided on the basis of the slurry feed rate. Emissions from the kiln are controlled with an ESP, and clinker cooler emissions are controlled with a fabric filter. Only controlled emissions were measured.

Particulate matter emissions were measured using Method 5 (front and back half); no information was provided on the method used to measure CO_2 emissions. The report states that the trace metal analysis was performed using spectroscopy, but no other details are provided. Two PM runs were conducted on the kiln stack and three runs were conducted on the clinker cooler stack. The tests on the kiln were interrupted due to inclement weather, but the data were considered to be representative.

Emission factors were developed for filterable and condensible PM emissions and for the emissions of 12 trace metals, including Sb, Be, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Sr, V, and Zn. The samples also were analyzed for arsenic but the concentration was below the detection limit. There was insufficient information to develop emission factors for CO_2 emissions.

The clinker cooler emission data for filterable and condensible PM are rated B. The test methodology was sound and no problems were reported, but the report lacked adequate documentation for a higher rating. The kiln PM test data are rated C because only two test runs were conducted. The trace metal emission data are unrated because only a single run was conducted, and details on the analytical procedure are not provided in the report.

4.2.1.3 Reference 3. This report documents measurements of filterable PM and condensible inorganic PM emissions from an air separator and a finishing mill, and SO_2, NO_x, and gaseous mercury emissions from an oil-fired rotary kiln. The emission test was sponsored by EPA as part of the development of an NSPS for portland cement plants. The test was conducted in 1971. The plant uses the wet process, and process rates were provided on the basis of slurry feed rate. Air separator emissions are controlled by two fabric filters in parallel, and the finishing mill emissions are controlled by a single fabric filter. Only controlled emissions were measured.

Particulate matter emissions were measured using Method 5 (front and back half). Although back half PM catches are reported in the results of the tests on the finishing mill and air separator, these two processes should not emit condensible PM. Therefore, it is assumed that the back half catch is the result of an anomaly in the sampling and analytical procedures used. The test report does not include adequate information to determine the origin of this apparent anomaly.

Emissions of SO_2 and NO_x were measured using continuous monitors. Gaseous mercury emissions were measured by bubbling kiln stack gas through impingers containing an acidic solution of iodine monochloride. Three PM runs were conducted on the air separator and finishing mill stacks, three mercury, one SO_2, and one NO_x runs were conducted on the kiln.

Emission factors were developed for filterable PM emissions from the air separator and the finishing mill. The report indicates concentrations of SO_2, NO_x, and gaseous mercury emissions but does

not provide volumetric flow rates for the kiln stack. Therefore, inadequate information was available to calculate emission factors for SO_2, NO_x, and gaseous mercury emissions.

The air separator and finishing mill emission data for filterable PM are rated B. The test methodology was sound, and no problems were reported, but the report lacked adequate documentation for a higher rating.

4.2.1.4 Reference 4. This report documents measurements of filterable PM, condensible inorganic PM, SO_2, NO_x, CO_2, and gaseous mercury emissions from two coal-fired rotary kilns that are ducted to a common stack. A trace metal analysis also was conducted on the total PM catch for run 1 of the kiln test. The emission test was sponsored by EPA as part of the development of an NSPS for portland cement plants. The test was conducted in 1971. The plant uses the dry process, and process rates were provided on the basis of feed rate. The kiln emissions are controlled by two fabric filters in parallel, each preceded by a multiclone. Only controlled emissions were measured.

Particulate matter emissions were measured using Method 5 (front and back half). Emissions of SO_2 and NO_x were measured using continuous monitors, but no details are provided on the methods and instruments used. Gaseous mercury emissions were measured by bubbling kiln stack gas through impingers containing an acidic solution of iodine monochloride. Carbon dioxide emissions were quantified using Orsat. The report states that the trace metal analysis was performed using spectroscopy, but no other details are provided. Three runs were conducted on the kiln for PM, SO_2, NO_x, and mercury; two CO_2 runs were conducted. All measurements were taken on the duct that collects gases from both fabric filters. The PM sample collected during the first run had to be discarded due to contamination of the sample, and the impinger water from the second and third PM runs was mistakenly mixed together.

Emission factors were developed for filterable and condensible PM from the two valid test runs and for SO_2, NO_x, CO_2, and gaseous mercury emissions from all three test runs on the kilns. Because the trace metal analysis was performed on the catch of run 1, which was not valid, no trace metal emission factors were developed. Because of the problems described above and the lack of adequate documentation, the PM emission data are rated C. The SO_2 and NO_x data are rated D because of the nonstandard method used and the general lack of documentation in the report. The mercury emission data are rated C due to the lack of adequate documentation, and the CO_2 emission data are rated C because data from only two test runs are provided.

4.2.1.5 Reference 5. This report documents measurements of filterable PM and condensible inorganic PM from a clinker cooler and a finishing grinding mill. A trace metal analysis was also conducted on the total PM catch from one run on each of the sources tested. The emission test was sponsored by EPA as part of the development of an NSPS for portland cement plants. The test was conducted in 1971. The plant uses the wet process, and process rates were provided on the basis of slurry feed rate. The clinker cooler and finishing mill emissions are controlled with fabric filters, and only controlled emissions were measured.

Particulate matter emissions were measured using Method 5 (front and back half), and three PM runs were conducted. Although back half PM catches are reported in the results of the test on the finishing mill, this process should not emit condensible PM. Therefore, it is assumed that the back half catch is the result of an anomaly in the sampling and analytical procedures used. The test report does not include adequate information to determine the origin of this apparent anomaly.

Trace metal analyses of the PM catches also were performed using spark source mass spectroscopy and optical emission spectroscopy.

Emission factors were developed for filterable and condensible inorganic PM emissions from the clinker cooler and for filterable PM emissions from the finishing mill. Because of a discrepancy in the total catches indicated for the trace metal analyses and the corresponding total PM catches, emission factors were not developed for trace metal emissions. However, the report indicated that the following metals were detected in the sample: Sb, As, boron (B), Cr, Cu, Fe, Pb, lithium (Li), Mn, Hg, Ni, Se, Ag, Sr, tin (Sn), V, and Zn. The samples also were analyzed for Be, but the concentration of this element was below the detection limit.

The clinker cooler and finish grinding mill emission data for filterable and condensible PM are rated B. The test methodology was sound and no problems were reported, but the report lacked adequate documentation for a higher rating.

4.2.1.6 Reference 6. This report documents measurements of filterable PM, condensible inorganic PM, SO_2, NO_x, and gaseous Hg emissions from a rotary kiln that was fired with natural gas and No. 6 fuel oil. A trace metal analysis also was conducted on the PM filter catch from one run. The emission test was sponsored by EPA as part of the development of an NSPS for portland cement plants. The test was conducted in 1971. The plant uses the wet process, and process rates were provided on the basis of the slurry feed rate. The kiln emissions are controlled by a fabric filter that exhausts to 12 stacks in parallel. Both uncontrolled and controlled SO_2 emissions were measured, but only controlled PM, NO_x, and mercury emissions were measured.

Particulate matter emissions were measured using Method 5 (front and back half), inlet SO_2 emissions were measured using Method 6, and outlet SO_2 and NO_x emissions were measured using Methods 7 and 8, respectively. Gaseous Hg emissions were measured by bubbling kiln stack gas through impingers containing an acidic solution of iodine monochloride. The trace metal analyses were performed using spark source mass spectrography and optical emission spectrography. However, emission factors could not be developed for trace metals because of the lack of details on total PM catch.

One PM run was conducted on each pair of stacks (for six pairs, total) for natural gas and fuel oil separately. One inlet and two outlet SO_2 runs were conducted for each type of fuel. Two NO_x runs were conducted for natural gas firing, and one run for fuel oil firing. Two Hg runs were conducted for gas-firing. Emission factors were developed for filterable and condensible PM, SO_2, NO_x, and gaseous Hg emissions from the kiln fired with natural gas and for filterable and condensible PM, SO_2, and NO_x from the kiln fired with fuel oil.

For all tests, the testing methodology was sound. However, the data were downrated because of a lack of detail in documentation and for the following reasons. The PM data are rated D. Although six measurements were made (one per pair of stacks), the six measurements constitute only one run of the entire emission stream. The inlet SO_2 data for both gas and fuel oil firing, and the NO_x data for fuel oil firing are unrated because only one run was conducted for each of the tests. The outlet SO_2 data and the NO_x data for gas-firing are rated C because only two runs were conducted and the report lacked adequate documentation. The Hg data are rated D because the report does not provide process or volumetric flow rates for the Hg runs; the Hg emission factors were developed using average process and

flow rates from the other tests. In addition, a nonstandard method was used to measure Hg emissions.

4.2.1.7 Reference 7. This report documents measurements of filterable PM, condensible inorganic PM, CO_2, and SO_2 emissions from a gas-fired rotary kiln. The emission test was sponsored by EPA as part of the development of an NSPS for portland cement plants. The test was conducted in 1971. The plant uses the wet process, and process rates were provided on the basis of the slurry feed rate. Kiln emissions are controlled with a fabric filter, and only controlled emissions were measured.

Particulate matter emissions were measured using Method 5 (front and back halves), and SO_2 emissions were measured using Method 8. The report does not specify the method used to quantify CO_2 emissions. Three PM runs and four SO_x runs were conducted.

Emission factors were developed for PM and SO_2 emissions; insufficient information was available to develop emission factors for CO_2 emissions. The test report noted that process operation was interrupted several times during the test due to excessive pressure drop across the fabric filter, visible emissions from leaking filter bags, and breakdown of dust removal equipment.

The emission data for filterable and condensible inorganic PM are rated C. Although the test methodology was sound, a higher rating is not justified due to lack of adequate documentation and recurring process upsets during the test. The SO_2 emission data also are rated D for the same reasons stated above for the PM test. In addition, process and volumetric flow rates for two of the four SO_2 runs were not provided and average rates had to be used to develop emission factors.

4.2.1.8 Reference 8. This report documents measurements of filterable PM and condensible inorganic PM emissions from a raw mill weigh hopper, a raw mill, a raw mill air separator, a finishing mill weigh hopper, a finishing mill, and a finishing air separator. Trace metal analyses also were conducted on the total PM catches from one run on each of the six sources. The emission test was sponsored by EPA as part of the development of an NSPS for portland cement plants. The test was conducted in 1971. The plant uses the dry process, and process rates were provided on the basis of the feed rate.

All six sources tested are controlled with fabric filters, and only controlled emissions were measured. Particulate matter emissions were measured using Method 5 (front and back half), and two test runs were conducted on the each of the six sources. Although back half PM catches are reported in the results of the tests on all of the sources, these processes should not emit condensible PM. Therefore, it is assumed that the back half catch is the result of an anomaly in the sampling and analytical procedures used. The test report does not include adequate information to determine the origin of this apparent anomaly.

The report states that the trace metal analyses were performed using emission spectroscopy, but no other details are provided. The samples were analyzed for Sb, As, Be, Cd, Cr, Cu, Fe, Pb, Mn, Ni, Sr, V, and Zn. Emission factors were developed for filterable PM emissions from the six sources tested. Emission factors also were developed for all of the trace metals listed above with the exception of arsenic and vanadium, which were below the detection limit in all samples.

The PM emission data are rated C. The test methodology was sound and no problems were reported, but only two test runs were conducted, and the report lacked adequate documentation for a

higher rating. The trace metal emission data are unrated because only a single run was conducted, and details on the analytical procedure are not provided in the report.

4.2.1.9 Reference 9. This report documents measurements of filterable PM and condensible inorganic PM emissions from primary limestone crushing, primary limestone screening, primary limestone transfer (conveyor discharge), and secondary screening and crushing combined. The emission test was sponsored by EPA as part of the development of an NSPS for stone crushing operations. The test was conducted in 1974. Process rates were provided on the basis of feed rate.

All four sources tested for PM emissions are controlled with fabric filters, and only controlled emissions were measured. Particulate matter emissions were measured using Method 5 (front and back half). Four test runs were conducted on the primary limestone crushing and screening, and three test runs were conducted on primary limestone transfer and secondary screening and crushing. Although back half PM catches are reported in the results of the tests on all of the sources, these processes should not emit condensible PM. Therefore, it is assumed that the back half catch is the result of an anomaly in the sampling and analytical procedures used. The test report does not include adequate information to determine the origin of this apparent anomaly.

One of the four runs on the primary crusher was not conducted under the acceptable limits (90 to 110 percent) for isokinetic conditions. All four runs on the primary screen were interrupted by process upsets that resulted in anisokinetic conditions. No problems were reported for the tests on the primary limestone transfer and secondary screening and crushing. Emission factors were developed for filterable PM emissions from the four sources tested.

The PM emission data for primary crushing, primary limestone transfer, and secondary screening and crushing are rated B. The test methodology was sound and no problems were reported, but the report lacked adequate documentation for a higher rating. The emission data for primary screening are rated C due to anisokinetic sampling conditions.

4.2.1.10 Reference 10. This report documents measurements of filterable PM and particle size distribution from a dry rotary kiln that is equipped with a suspension preheater. The emission test was sponsored by EPA as part of a study to characterize emissions of inhalable PM emissions from the cement industry. The test was conducted in 1981. Process rates were provided on the basis of feed rate and clinker production rate. The kiln is fired with a combination of coal and coke.

Emissions from the kiln are controlled with a fabric filter. Both uncontrolled and controlled emissions were measured. Uncontrolled PM emissions were measured using Method 5 (front half only), and controlled PM emissions were measured using Method 17. Four test runs were conducted on the fabric filter inlet and two test runs on the fabric filter outlet. Emission factors were developed for uncontrolled and controlled filterable PM emissions from the kiln.

Particle size distribution was measured on the uncontrolled and controlled emissions using cascade impactors with a preseparator. The particle size distribution measurements were taken concurrently with the Method 5 and Method 17 PM measurements. The results of the particle size tests are described in more detail in Reference 79.

The uncontrolled PM and particle size distribution data are rated A. The test methodology was sound, and the report includes adequate documentation. The controlled PM data are downrated to C because only two runs were conducted.

4.2.1.11 Reference 11. This report documents measurements of filterable PM and particle size distribution from a rotary kiln with preheat supplied from the clinker cooler. The emission test was sponsored by EPA as part of a study to characterize emissions of inhalable PM emissions from the cement industry. The test was conducted in 1981. Process rates were provided on the basis of dry feed rate and clinker production rate. The kiln is fired with pulverized coal and uses the wet process.

Emissions from the kiln are controlled with an ESP. Both uncontrolled and controlled emissions were measured. Uncontrolled PM emissions were measured using Method 5 (front half only), and controlled PM emissions were measured using Method 17. Four test runs were conducted on the ESP inlet and two test runs on the ESP outlet.

Particle size distribution was measured on the uncontrolled and controlled emissions using cascade impactors with a preseparator. The particle size distribution measurements were taken concurrently with the Method 5 and Method 17 PM measurements. The results of the particle size tests are described in more detail in Reference 79.

Due to a dust layer in the inlet duct to the ESP, the sampling points locations had to be adjusted. Although it was not known what effect this modification had on the tests, the unusually high uncontrolled emission rates indicate that the data are biased high. Emission factors were developed for uncontrolled and controlled filterable PM emissions from the kiln; size-specific emission factors also were developed.

The inlet PM data and particle size distribution data are rated D due to the problem described above. The outlet PM and particle size distribution data are rated C. The test methodology was sound, and the report includes adequate documentation, but only two runs were conducted.

4.2.1.12 Reference 12. This report documents measurements of filterable PM, condensible inorganic PM, and SO_2 emissions from four coal-fired rotary kilns. The emission test was conducted to demonstrate compliance with State regulations. The test was conducted in 1977. The plant uses the dry process, and process rates were provided on the basis of raw material feed and clinker production rates. The sulfur content of the coal was reported as 2.84 percent. The plant has two stacks, each of which serves two of the kilns. Each of the stacks is equipped with a multiclone and an ESP to control kiln emissions, and only controlled emissions were measured.

Particulate matter emissions were measured using Method 5 (front and back half), and SO_2 emissions were measured using Method 8. Three PM runs were conducted on each of the two stacks. Eight SO_2 runs were conducted on one of the stacks, and four SO_2 runs were conducted on the other stack. Emission factors were developed for controlled PM and SO_2 emissions. Because of the relatively high SO_2 emission rates measured, the data were combined and treated as a measurement of SO_2 emissions from one kiln.

The kiln emission data for PM and SO_2 are rated B. The test methodology was sound, and no problems were reported, but the report lacked adequate documentation for a higher rating.

4.2.1.13 Reference 13. This report documents measurements of filterable PM, condensible inorganic PM, and SO_2 emissions from a coal-fired rotary kiln. The emission test was conducted to demonstrate compliance with State regulations. The test was conducted in 1977. The plant uses the wet process, and process rates were provided on the basis of raw material (dry solids) feed and clinker production rates.

Emissions are controlled with an ESP, and both uncontrolled and controlled emissions were measured. Particulate matter emissions were measured using Method 5 (front and back half), and SO_2 emissions were measured using Method 8. Six uncontrolled and 12 controlled PM runs were conducted. For three of the uncontrolled and controlled runs, an insufflation rate of 6 tons/hr was reported, and for three uncontrolled and controlled runs, an insufflation rate of 12 tons/hr was reported. The kiln normally operates with a 6-ton/hr insufflation rate. Six SO_2 runs were conducted. The sulfur content of the coal was 2.44 percent for the first three runs and 2.98 percent for the last three runs. Emission factors were developed for uncontrolled and controlled PM and for uncontrolled SO_2 emissions. The PM emission factors developed for the kiln operating at both insufflation rates were comparable.

The kiln emission data for PM and SO_2 are rated B. The test methodology was sound and no problems were reported, but the report lacked adequate documentation for a higher rating.

4.2.1.14 Reference 14. This report documents measurements of filterable PM, condensible inorganic PM, and CO_2 emissions from four coal-fired rotary kilns. The emission tests were conducted in 1979 to demonstrate compliance with State regulations. Three of the kilns (Nos. 1, 3, and 4) tested use the dry process, and the fourth kiln (No. 5) uses the wet process. Process rates were provided on the basis of feed and clinker production rates.

Emissions from each of kilns 1, 3, and 4 first pass through a cooling tower and then through a combination of multiclone with ESP. Kiln No. 5 is operated with a preheater/pelletizer system; emissions from the preheater are controlled with a double-chamber ESP. Only controlled emissions measurements were documented in the report. Particulate matter emissions were measured using Method 5 (front and back half), and CO_2 emissions were measured using Orsat. Six runs were conducted on each of the four kilns. However, for one of the kilns, the data needed to develop emission factors were provided for only two runs. Emission factors were developed for controlled PM and for uncontrolled CO_2 emissions. Additional runs also were conducted on kiln 5 with the exhaust gas bypassing the ESP to either one or two raw mills. However, emission factors were not developed for these runs because the gas sampled did not represent all of the kiln emissions.

The data for PM and CO_2 emissions from kilns 1, 3, and 4, are rated B. The test methodology was sound and no problems were reported, but the report lacked adequate documentation for a higher rating. The emission data for kiln 5 are rated C because only two test runs were conducted.

4.2.1.15 Reference 15. This report documents measurements of filterable PM and condensible inorganic PM from a clinker cooler. The emission test was conducted in 1980 to demonstrate compliance with State regulations. The plant has three dry process coal-fired rotary kilns, all of which feed a common clinker cooler. Process rates were provided on the basis of kiln feed and clinker cooler feed rates.

Emissions from the clinker cooler are controlled with a wet gravel bed filter. Only controlled emissions were measured. Particulate matter emissions were measured using Method 5 (front and back half), and three test runs were conducted. Emission factors were developed for controlled filterable and condensible inorganic PM.

The clinker cooler PM emission data are rated A. The test methodology was sound and no problems were reported.

4.2.1.16 Reference 16. This report documents measurements of filterable PM, condensible inorganic PM, SO_2, and CO_2 from a dry process coal-fired rotary kiln. The emission tests were conducted in 1980 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker cooler production rates.

Emissions from the kiln are controlled with a combination of cyclone and fabric filter. Only controlled emissions were measured. Particulate matter emissions were measured using Method 5 (front and back half), and SO_2 emissions were measured using Method 6. The method used to measure CO_2 emissions was not specified, although the report states that all testing was conducted in accordance with EPA reference test methods. Three test runs were conducted. Emission factors were developed for controlled filterable and condensible inorganic PM, SO_2, and CO_2 emissions.

The PM data are rated A. The test methodology was sound, no problems were reported, and the documentation was adequate. The CO_2 data are rated C because the test method was not specified. The SO_2 data are rated D because the wide range in emission rates (26.9 lb/hr for the first run and 5.3 lb/hr for the last two runs) is indicative of testing problems.

4.2.1.17 Reference 17. This report documents measurements of SO_2, SO_3, and CO_2 from three dry process coal-fired rotary kilns. The kilns are equipped with suspension preheaters. The emission tests were conducted in 1980 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed rates.

The kilns are equipped with fabric filters to control emissions, and only controlled emissions were reported. Emissions of SO_2 and SO_3 were measured using Method 6, and CO_2 emissions were measured by Orsat. Three test runs were conducted on each of the three kilns. Emission factors were developed for SO_3 and CO_2 emissions. For six of the nine SO_2 runs, SO_2 emissions are reported as zero. Therefore, emission factors were not developed for SO_2 emissions.

The emission data for SO_3 and CO_2 emissions are rated B. The test methodology was sound, and no problems were reported. However, the documentation was inadequate to warrant a higher rating.

4.2.1.18 Reference 18. This report documents measurements of filterable PM, SO_2, SO_3, CO_2, ammonium (NH_4^+), chloride (Cl^-), K, Na, and sulfate ($SO_4^{-2)}$ from two wet process coal-fired rotary kilns. The emission tests were conducted in 1981 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed rates. The sulfur content of the coal was 1.06 percent.

The kilns are equipped with ESP's, and only controlled emissions were reported. Emissions of filterable PM were measured using Method 5; CO_2 emissions were measured by Orsat; emissions of NH_4^+, K, Na, and SO_4^{-2} were quantified from the Method 5 PM catch; and emissions of SO_2, SO_3, and

chloride were measured by analyzing the back half of the Method 5 sampling train. To quantify SO_2 emissions, one of the impingers was filled with a 6 percent solution of hydrogen peroxide. Three test runs were conducted on both of the kilns. Emission factors were developed for filterable PM, SO_2, SO_3, CO_2, NH_4^+, Cl^-, K, Na, and SO_4^{-2}.

The PM, CO_2, K, Na, and SO_4^{-2} emission data are rated B. The test methodology was sound, and no problems were reported. However, the documentation was inadequate to warrant a higher rating. The emission data for SO_2, SO_3, and Cl^- are rated C because nonstandard test methods were used.

4.2.1.19 Reference 19. This report documents measurements of filterable PM, SO_2, NO_x, and CO_2 from four wet process coal-fired rotary kilns. The emission tests were conducted in 1981 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker production rates. The sulfur content of the coal was reported as 3.55 percent.

Three of the kilns (Nos. 1, 2, and 3) are ducted to a common stack (stack 2) and are controlled with an ESP. Kiln 4 is ducted to a separate ESP and stack (stack 4). Controlled emissions from stack 2, and both uncontrolled and controlled emissions from stack 4 were measured. Emissions of PM were measured using Method 5, SO_2 emissions were measured using Method 6, NO_x emissions were measured using Method 7, and CO_2 emissions were measured by Orsat. The number of valid test runs conducted included 29 for PM, 30 for SO_2, 20 for CO_2, and 20 for NO_x. Emission factors were developed for filterable PM, SO_x, NO_x, and CO_2 emissions.

The filterable PM, SO_x, NO_x, and CO_2 emission data are rated B. The test methodology was sound, and no problems were reported. However, the documentation was inadequate to warrant a higher rating.

4.2.1.20 Reference 20. This report documents measurements of filterable PM emissions from a coal-fired rotary kiln and a clinker cooler. The type of process was not specified in the report. The emission tests were conducted in 1983 to demonstrate compliance with State regulations. Process rates were provided on the basis of the kiln and clinker cooler feed rate.

The kiln emissions are ducted to an ESP and fabric filters in parallel; the clinker cooler emissions are ducted to a fabric filter. Three runs were conducted on each source, and only controlled emissions were measured. Emission factors were developed for filterable PM emissions from the clinker cooler. However, because of the unusual configuration of control devices on the kiln, the test data are not useful for developing kiln emission factors.

The emission data are rated B. The test methodology was sound, and no problems were reported. However, the documentation was inadequate to warrant a higher rating.

4.2.1.21 References 21 and 22. Reference 21 is an emission test report that documents measurements of filterable PM, SO_2, NO_x, CO, and CO_2 emissions from a dry process coal-fired rotary kiln that is equipped with a suspension preheater/flash calciner. An unspecified crusher and a grate-type clinker cooler also were tested for PM emissions. The emission tests were conducted in 1983 to demonstrate compliance with State regulations. The process rates included in the report tables were indicated as production rates, but no other information was provided. The report does not include a

process description. However, Reference 22, which is a technical paper about the facility, includes a process description of the facility.

Emissions from the kiln, crusher, and clinker cooler are each controlled with a separate fabric filter. Method 5 was used to measure PM emissions, and continuous monitors were used to quantify emissions of SO_2, NO_x, CO, and CO_2. Three runs were conducted on each source, and only controlled emissions were measured. Due to negative filter weights on most of the runs, emission factors were not developed for PM emissions from the kiln and clinker cooler. In addition, due to a lack of information, emission factors also were not developed for crusher emissions.

The SO_2, NO_x, CO, and CO_2 emission data are rated C due to the poor documentation of the test methods and the basis for the process rates.

4.2.1.22 Reference 23. This report documents measurements of PM, SO_2, and NO_x emissions from a coal-fired rotary kiln and PM emissions from a clinker cooler. The type of process was not specified in the report. The emission test were conducted in 1983 as part of a State source survey. Process rates were provided on the basis of kiln feed and clinker production.

Emissions from the kiln are controlled with a fabric filter. Only controlled kiln emissions were measured. Particulate matter emissions were measured using Method 5 (front and back half); the report states that SO_2, NO_x, and CO_2 emissions were measured in accordance with standard EPA test methods but does not indicate the methods used. Three test runs were conducted. Emission factors were developed for controlled filterable PM, condensible inorganic PM, SO_2, NO_x, and CO_2 emissions from the kiln.

Emissions from the clinker cooler are controlled with a gravel bed filter. Three runs were conducted on the clinker cooler and only controlled emissions were measured. Emission factors were developed for filterable PM and condensible inorganic PM emissions from the clinker cooler.

The emission data from the kiln test were not rated because the type of process was not specified. The clinker cooler data are rated B. The test methodology appeared to be sound, no problems were reported, and the documentation was inadequate to warrant a higher rating. Because 3. fyrite may have been used to measure CO_2 concentrations, the CO_2 data are rated C.

4.2.1.23 Reference 24. This report documents measurements of filterable PM, condensible inorganic PM, SO_2, SO_3, SO_4^{-2}, NO_x, CO, TOC, and CO_2 from a dry process coal-fired rotary kiln. The kiln is equipped with a suspension preheater/flash calciner, and the facility is the same as the facility tested in Reference 21. An unspecified crusher and a grate-type clinker cooler were also tested. The emission tests were conducted in 1984 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed rate for the kiln test and clinker feed rate for the test on the clinker cooler. Due to the lack of adequate information, the crusher test data were discarded.

Emissions from the kiln and clinker are controlled by separate fabric filters, and only controlled emissions were measured. Emissions of PM (front and back half) were measured using Method 5; sulfate emissions were measured using Method 8; and TOC emissions were measured with a gas chromatograph-flame ionization detector (GC-FID) procedure. Emissions of SO_2, NO_x, CO, and CO_2 were measured with continuous monitors in accordance with California Air Resources Board (CARB)

Method 1-100. This method is comparable to EPA Methods 6C, 7E, 10, and 3A for measuring SO_2, NO_x, CO, and CO_2, respectively. However, CARB Method 1-100 uses separate instrument analyzers connected in parallel with a manifold to simultaneously sample for different types of gases.

The emission data are rated B. The test methodology was sound, and no problems were reported. However, the documentation was inadequate to warrant a higher rating.

4.2.1.24 Reference 25. This report documents measurements of filterable PM and CO_2 from a dry process coal-fired rotary kiln that is equipped with a suspension preheater. The report also documents emissions from a Loesche-type raw mill and a grate-type clinker cooler. The emission tests were conducted in 1984 to demonstrate compliance with State regulations. Process rates were provided for the kiln and the clinker cooler on the basis of kiln feed rate for the kiln test only.

Because the raw mill is ducted to the same stack as the kiln, the emission data measured while the kiln were operating are of little use. However, measurements also were made with the raw mill not operating, and the data from those runs should be representative of kiln emissions.

Emissions from the kiln and raw mill are controlled with an ESP, and clinker cooler emissions are controlled with a combination of a cyclone and gravel bed filter in series. Only controlled emissions were measured. Emissions of filterable PM were measured using Method 5, and CO_2 emissions were quantified by Orsat. Using the measurements made while the raw mill was not operating, emission factors were developed for filterable PM and CO_2 emissions from the kiln. Emission factors also were developed for filterable PM emissions from the clinker cooler.

The emission data are rated B. The test methodology was sound, and no problems were reported. However, the documentation was inadequate to warrant a higher rating.

4.2.1.25 Reference 26. This report documents measurements of filterable PM, SO_2, and CO_2 from a wet process coal-fired rotary kiln. The emission tests were conducted in 1984 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed rate in gallons per minute of slurry. The report also states that the capacity of the kiln is 400 gal/min, which corresponds to approximately 1,500 tons/day of clinker. The sulfur content of the coal was reported as 2.50 percent.

Emissions from the kiln are controlled with an ESP, and only controlled emissions were measured. Emissions of filterable PM were measured using Method 5; SO_2 emissions were measured using Method 6; and CO_2 emissions were quantified by Orsat. Emission factors were developed for filterable PM, SO_2, and CO_2 emissions from the kiln.

Although the test methodology was sound, and no problems were reported, the emission data are rated C due to a lack of adequate documentation and the uncertainty in process rates.

4.2.1.26 Reference 27. This report documents an emission test at the same facility as in References 21 and 24. The emission tests included measurements of filterable PM, condensible inorganic PM, SO_2, SO_3, SO_4^{-2}, NO_x, CO, TOC, and CO_2 from a dry process coal-fired rotary kiln. The kiln is equipped with a suspension preheater/flash calciner. An unspecified crusher and a grate-type clinker cooler also was tested. The emission tests were conducted in 1985 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed rate for the kiln test and clinker feed

rate for the test on the clinker cooler. Due to the lack of adequate information, the crusher test data were discarded.

Emissions from the kiln and clinker are controlled by separate fabric filters, and only controlled emissions were measured. Emissions of PM (front and back half) were measured using Method 5; sulfate emissions were measured using Method 8; emissions of SO_2, NO_x, CO, and CO_2 were measured with continuous monitors in accordance with CARB Method 1-100; and TOC emissions were measured with a GC-FID procedure.

The emission data are rated B. The test methodology was sound, and no problems were reported. However, the documentation was inadequate to warrant a higher rating.

4.2.1.27 Reference 28. This report documents measurements of filterable PM, SO_2, NO_x, and CO_2 from a wet process coal-fired rotary kiln. The emission tests were conducted in 1985 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker production rates. The sulfur content of the coal was reported as 1.78 percent.

Emissions from the kiln are controlled with an ESP, and only controlled emissions were measured. Emissions of filterable PM were measured using Method 5; SO_2 emissions were measured using Method 6; NO_x emissions were quantified using Method 7; and CO_2 emissions were quantified by Orsat. Emission factors were developed for filterable PM, SO_2, NO_x, and CO_2 emissions from the kiln.

The emission data are rated B. The test methodology was sound, and no problems were reported. However, the documentation was inadequate to warrant a higher rating.

4.2.1.28 Reference 29. This report documents measurements of filterable PM, SO_2, NO_x, and CO_2 from a wet process coal-fired rotary kiln. The emission tests were conducted in 1981 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker production rates. The sulfur contents of the coal and raw material were reported as 1.33 percent and 0.08 percent, respectively.

Emissions from the kiln are controlled with an ESP, and only controlled emissions were measured. Emissions of filterable PM were measured using Method 5; SO_2 emissions were measured using Method 6; NO_x emissions were quantified using Method 7; and CO_2 emissions were quantified by Orsat. Three runs of PM and SO_2, 6 runs of CO_2, and 12 runs of NO_x emissions were conducted. Emission factors were developed for filterable PM, SO_2, NO_x, and CO_2 emissions from the kiln.

The emission data are rated C. Although the test methodology was sound, the report does not include a process description and generally is lacking in details.

4.2.1.29 Reference 30. This report documents measurements of filterable PM, SO_2, NO_x, and CO_2 from the same wet process coal-fired rotary kiln for which emission measurements were documented in Reference 29. The emission tests were conducted in 1981 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker production rates. The sulfur content of the coal was reported as 1.33 percent.

Emissions from the kiln are controlled with an ESP. Uncontrolled and controlled PM emissions were measured, ESP inlet and outlet SO_2 emissions were measured, and uncontrolled NO_x and CO_2 emissions were measured. Emissions of filterable PM were measured using Method 5; SO_2 emissions were measured using Method 6; NO_x emissions were quantified using Method 7; and CO_2 emissions were quantified by Orsat. Six runs of PM and SO_2 emissions were performed (3 at the ESP inlet and 3 at the ESP outlet), as were 6 runs of CO_2 emissions, and 12 runs of NO_x emissions. Emission factors were developed for uncontrolled and controlled filterable PM emissions and for uncontrolled SO_2, NO_x, and CO_2 emissions from the kiln.

The emission data are rated C. Although the test methodology was sound, the report does not include a process description and generally is lacking in details.

4.2.1.30 Reference 31. This report documents measurements of filterable PM, condensible inorganic PM, SO_2, NO_x, CO, and CO_2 from a precalciner dry process coal-fired rotary kiln. The emission tests were conducted in 1985 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed.

Emissions from the kiln are controlled with an ESP, and only controlled emissions were measured. Emissions of filterable PM were measured using Method 5; SO_2, NO_x, CO, and CO_2 emissions were measured with continuous monitors in accordance with CARB Method 1-100. Three runs were conducted. Emission factors were developed for filterable PM, condensible inorganic PM, SO_2, NO_x, CO, and CO_2 emissions from the kiln.

The emission data are rated B. The test methodology was sound, and no problems were reported. However, the documentation was inadequate to warrant a higher rating.

4.2.1.31 References 32, 33, and 34. These reports document measurements of filterable PM emissions from two coal-fired kilns and a clinker cooler (Reference 32), measurements of filterable PM, SO_2, and sulfuric acid emissions from two coal-fired kilns (Reference 33), and measurements of filterable PM and SO_2 emissions from three coal-fired kilns (Reference 34). The emission tests were conducted in 1976 and 1978 to demonstrate compliance with State regulations. The reports do not specify the type of process used, and process rates are not included in the reports. Therefore, the reports could not be used to develop emission factors.

4.2.1.32 Reference 35. This document consists primarily of summary tables of measurements of NO_x from two dry process coal-fired rotary kilns. The emission tests were conducted in 1987. Process rates were provided on the basis of clinker production. The report states that low-sulfur coal was used but does not specify the sulfur content of the coal.

Emissions from the kiln are controlled with a fabric filter. Only controlled emissions of NO_x were measured, using continuous emission monitoring, and data were provided for daily NO_x emission levels for three consecutive months. Emission factors were developed for NO_x emissions.

The NO_x data are rated C due to the general lack of adequate documentation.

4.2.1.33 Reference 36. This reference is a four-volume report on the demonstration of the feasibility of reducing NO_x emissions from a portland cement rotary kiln, which is controlled with a fabric

filter. The report includes continuous emission monitor (CEM) data on NO_x emissions from a coal-fired dry process kiln for a 14-month period in 1984 and 1985 following process modifications to reduce NO_x emissions. The process changes consist of using more secondary air from the clinker cooler for combustion; using redesigned heat exchange equipment to reduce fuel consumption; using an indirect coal firing system; using a redesigned burner pipe to improve flame control; and using improved instrumentation, raw material chemical uniformity, flame control, and personnel training to improve kiln stability.

The report describes the instruments used and the quality assurance procedures developed during the course of the project. However, it is not clear from the report if the sampling and analytical methods were comparable to standard EPA methods.

Process operating rates are not provided, but the report includes NO_x emission factors in units of lb/ton of clinker at 6-minute intervals with hourly and daily averages for the entire 14-month period. The overall average NO_x emission factor for the test period was reported as 5.8 lb/ton. Based on the results of eight emission tests conducted between 1974 and 1981, the process modifications achieved a 26 percent reduction in NO_x emissions. The NO_x CEM data are rated B. Although the methodology was sound, data on process operating rates is limited.

Attachment C of the report includes reports for two of the eight previous emission tests referenced in the document. The first of these reports includes data on CO and NO_x emissions. Samples were collected in a mylar bag, evacuated to a grab bulb, and analyzed. These data are rated D due to the nonstandard test methodology. In the second test report included in Attachment C of the reference, SO_2 and NO_x emissions were measured using Methods 6 and 7 (instrument analyzers). These data are rated B.

4.2.1.34 Reference 37. This report documents measurements of filterable PM, SO_2, NO_x, TOC, and VOC from a dry process coal-fired rotary kiln. The emission test was conducted in 1989 to quantify emissions of various pollutants. The report includes hand-written process rates on the basis of clinker production.

Emissions from the kiln are controlled with a fabric filter. Only controlled emissions were measured. Particulate matter emissions were measured using the Michigan Department of Natural Resources Method 5B. Sulfur dioxide and NO_x emissions were measured using a continuous analyzer. Methods 25 and 25A were used to measure VOC and TOC, respectively, which were reported on a molecular weight basis as methane. Three test runs were conducted. Emission factors were developed for filterable PM, SO_2, NO_x, TOC, and VOC.

The SO_2 and NO_x data are rated B. The test methodology was sound, no problems were reported, and the documentation was adequate. The PM, TOC, and VOC data are rated C because the report did not include data for individual runs.

4.2.1.35 Reference 38. This reference consists of selected pages from a report of an emission test conducted on a wet process rotary kiln. The kiln was being co-fired with coal and waste fuel at the time of the test. Results of SO_2 emissions are reported, but process rates are not included. Therefore, emission factors were not developed from the data.

4.2.1.36 References 39. This reference consists of summaries of several test reports and includes data summaries and other test documentation for measurements of SO_2, NO_x, CO, and CO_2 from three dry process coal-fired rotary kilns. Two of the kilns are located at the Southwestern Portland Cement Victorville Plant, and the third kiln is located at the Southwestern Portland Cement Black Mountain Plant. Emissions from the kilns at both locations are controlled with fabric filters. The sulfur contents of the coal for two of the tests are reported as 0.71 percent and 0.81 percent.

The only data for the Victorville facility are from a single-run test conducted on each kiln in 1980. Because only one test run was performed on each kiln, the data from the Victorville Plant were not used to develop emission factors.

Test data for the Black Mountain facility are included for one test conducted in 1980 and three tests conducted in 1984. The test summaries include data on one test run for SO_2, NO_x, CO, and CO_2 emissions; data on one test run from a second test for NO_x and CO_2 emissions; data on one test run from a third test for SO_2, NO_x, and CO_2 emissions; and data on three test runs from a fourth test for SO_2, NO_x, and CO_2 emissions. Nitrogen oxide and SO_2 emissions were measured using EPA Methods 7 and 8, respectively. Carbon monoxide was analyzed using gas chromatography, and CO_2 emissions were quantified using Orsat.

The data from tests that consist of a single run generally are not used for emission factor development. However, because several one-run tests and one three-run test were conducted on the same kiln, the data were combined for the purposes of developing average emission factors.

The SO_x, NO_x, and CO_2 test data from the Black Mountain Plant are rated D for a combination of reasons. The documents included little documentation; average, rather than run-specific process rates were provided; and volumetric flow rates were based on fuel analysis rather than on direct measurement. The CO emission data are unrated because the results of only a single run are reported.

4.2.1.37 Reference 40. This document consists of selected pages from a test report that documents measurements of PM, hydrochloric acid (HCl), SO_2, and CO_2 from a wet process kiln fired with coal. The kiln is that the same kiln for which emission measurements were documented in Reference 26. Emissions from the kiln are controlled with an ESP. The test included measurements of emissions while the same kiln was fired with a combination of coal and waste fuel, but data on that test were not included in the reference. The sulfur content of the coal was reported as 2.72 percent.

The test method used to measure PM emissions was not indicated in the reference. Method 6 was used to quantify SO_2. Hydrochloric acid emissions were quantified using a modified Method 5 sampling train. The first two impingers contained a solution of sodium hydroxide, the third impinger was empty, and the fourth impinger contained silica gel. The samples were analyzed with the mercuric nitrate method. Emission factors were developed for emissions of filterable PM, SO_2 and HCl emissions. No information is provided on the method used to measure CO_2, and the reference does not include adequate information for developing CO_2 emission factors.

The test data are rated C because of the lack of adequate documentation.

4.2.1.38 Reference 41. This report documents measurements of filterable PM, NO_x, and SO_2 emissions from a coal-fired wet process rotary kiln. The emission test was conducted in 1985 to

demonstrate compliance with State regulations. The report does not include process rates and could not be used to develop emission factors.

4.2.1.39 References 42 and 43. These reports document measurements of filterable PM, NO_x, SO_2, SO_4^{-2}, NH_4^+, Cl^-, K, Na, nitrates (NO_3), and fluoride (F^-) from two wet process coal-fired rotary kilns. These kilns are the same kilns for which emission measurements are documented in Reference 18. The purpose of the tests was to identify the pollutants that were causing a detached plume of 100 percent opacity that formed within a short distance of the stacks. Reference 42 documents emission tests on both kilns for filterable PM, NO_x, SO_2, SO_4^{-2}, NH_4^+, Cl^-, K, and Na, and Reference 43 documents an emission tests for on one of the kilns for filterable PM, NO_x, SO_4^{-2}, NH_4^+, Cl^-, K, Na, NO_3, and F^- using an experimental procedure. The tests were conducted in 1982. Process rates were provided on the basis of kiln feed rate.

Emissions from the kilns are controlled with ESP's, and only controlled emissions were measured. In the initial tests (Reference 42), filterable PM emissions were measured using a combination of Methods 5 and 17 sampling trains in series. The other compounds were quantified by analyzing either the front half or the back half of the PM sampling train; details on the testing and analytical methods are not provided. Three test runs were conducted on each kiln.

For the experimental test, a modified Method 17 sampling train was used. The train was modified to introduce dilution air into the gas stream to cool the gas temperature. An analytical procedure similar to the procedure used in the initial test was used to quantify emissions of SO_2, SO_4^{-2}, NH_4^+, Cl^-, K, and Na. Three test runs were conducted.

Nitrogen oxide emissions were measured using Method 7. Twelve NO_x runs were conducted on each kiln. These tests were documented in Reference 18.

Emission factors were developed for controlled filterable PM, NO_x, SO_2, SO_4^{-2}, NH_4^+, Cl^-, K, Na, NO_3, and F^-. The PM and NO_x data are rated B. The methodology was sound, but the documentation was not in adequate detail to warrant a higher rating. The emission data for the other compounds are rated C due to the lack of adequate documentation and the nonstandard test methods used.

4.2.1.40 Reference 44. This report documents measurements of filterable PM, SO_2, SO_4^{-2}, NH_4^+, Cl^-, K, and Na from a wet process coal-fired rotary kiln. The facility is the same as that in References 18, 42, and 43. The stated purpose of the test was to determine the concentrations of the target pollutants in the stack emissions. The test was conducted in 1982. Process rates were provided on the basis of the kiln feed rate.

Emission from the kiln are controlled with an ESP, and only controlled emissions were measured. Method 5 was used to measure PM emissions. The other compounds were quantified by analyzing the back half of the PM sampling train. The back half of the sampling train included an impinger containing deionized water to absorb NH_4^+, Cl^-, K, and Na; an impinger containing 80 percent isopropyl alcohol to absorb SO_3; and an impinger containing a 6 percent solution of hydrogen peroxide to absorb SO_2. Three test runs were conducted.

Emission factors were developed for controlled filterable PM, SO_2, SO_4^{-2}, NH_4^+, Cl^-, and Na. The PM data are rated B. The methodology was sound, but the documentation was not in adequate detail

to warrant a higher rating. The emission data for the other compounds are rated C due to the lack of adequate documentation and the nonstandard test methods used.

4.2.1.41 References 45 and 46. These references include only a table of SO_x and NO_x emission factors developed from several tests conducted on a coal-fired wet process kiln. Due to the lack of information on test methods and control devices, the data were not considered for this revision of AP-42.

4.2.1.42 Reference 47. This reference consists of a single sheet of handwritten notes on an emission test conducted on a dry process rotary kiln. The facility is the same facility for which emission tests were documented in Reference 39. Because data are presented for a single run only and the reference lacks information on test methods and other aspects of the test, emission factors were not developed.

4.2.1.43 Reference 48. This reference documents measurements of NO_x, CO, CO_2, and SO_2 from three coal-fired wet process rotary kilns. The facility is the same as that in References 39 and 47. However, the tests were conducted on kilns other than those for which tests are documents in those references. The emission tests were conducted in 1980 as part of the application requirements for an operating permit for the kilns. Process rates were provided on the basis of the clinker production rate.

The report does not specify the type of control device used on the kiln stacks. The SO_2 emission test consisted of a single run on each kiln, and a nonstandard sampling train was used. Nitrogen oxide and CO samples were collected in a Tedlar bag connected to the dry gas meter. Three NO_x samples and one CO sample were collected from each of the kiln stacks. A single CO_2 measurement was taken using Orsat. Emission factors were developed for SO_2, NO_x, CO, and CO_2 emissions. The SO_2, CO, NO_x, and CO_2 data are unrated because only a single run was conducted.

4.2.1.44 Reference 49. This report documents measurements of NO_x emissions from a preheater/precalciner coal-fired rotary kiln. The emission test was conducted in 1987 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker cooler production rates.

Emissions from the kiln are controlled with an ESP. Nitrogen oxide emissions were measured using Method 7, and five runs were conducted. Emission factors were developed for NO_x emissions from the kiln.

The NO_x data are rated B. The test methodology was sound, and no problems were reported, but the documentation was inadequate to warrant a higher rating.

4.2.1.45 Reference 50. This reference consists of a letter that includes SO_2 and NO_x emission factors developed from the results of an emission test conducted on a coal-fired preheater/precalciner kiln in 1981. The letter states that Method 6 was used to measure SO_2 emissions and Method 7 was used to quantify NO_x emissions. The letter does not indicate the number of test runs conducted.

Due to the lack of documentation, the emission data are rated D.

4.2.1.46 Reference 51. This reference includes selected pages from a report that documents measurements of filterable PM, NO_x, and SO_2 from a coal-fired preheater/precalciner kiln. The emission

test was conducted in 1986 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker production rate.

Emissions from the kiln are controlled with a fabric filter. Only controlled emissions were measured. The document states that all tests were conducted in accordance with standard EPA methods, but no information is included on sampling and analytical procedures. Three test runs were conducted. Emission factors were developed for filterable PM, SO_2, and NO_x emissions. The emission data are rated C due to the general lack of adequate documentation.

4.2.1.47 Reference 52. This reference includes selected pages from a report that documents measurements of filterable PM, SO_2, and CO_2 emissions from a preheater process coal-fired rotary kiln. The emission test was conducted in 1986 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker production rate. The sulfur content of the coal was reported as 1.5 percent.

Emissions from the kiln are controlled with two fabric filters, one for the kiln stack and one for the alkali bypass stack. Only controlled emissions were measured. Method 5, Method 6, and Orsat were used to measure emissions of filterable PM, SO_2, and CO_2, respectively. Three test runs were conducted. Emission factors were developed for filterable PM and SO_2 emissions based on the combined emissions from both stacks.

The emission data are rated B. Although standard test methods were used, the document lacked adequate information to warrant a higher rating.

4.2.1.48 Reference 53. This reference consists of a cover letter with summary tables for a series of emission tests for filterable PM, SO_2, NO_x, and CO_2 emissions from a preheater process coal-fired rotary kiln. The emission tests were conducted between 1982 and 1989 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker production rate.

Emissions from the kiln are controlled with two fabric filters, and only controlled emissions were measured. Method 5, Method 6, Method 7, and Orsat were used to measure emissions of filterable PM, SO_2, NO_x, and CO_2, respectively. Seven PM tests, 10 SO_2 tests, and 9 NO_x tests were conducted. In addition, data on CO_2 emissions from three tests are presented in the tables. The number of runs per test is not specified in the document. Emission factors were developed for filterable PM, SO_2, NO_x, and CO_2 emissions from the kiln.

The emission data are rated C. Although standard test methods were used, the document lacked adequate information to warrant a higher rating.

4.2.1.49 Reference 54. This reference consists of selected pages from a report that documents three emission tests on a preheater process coal-fired rotary kiln. The kiln was tested for emissions of filterable PM, SO_2, NO_x, CO, CO_2, TOC, VOC, and HCl in 1989 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker production rate. Emissions from the kiln are controlled with a fabric filter, and it is assumed that emissions were measured at the outlet of the control device only.

The test methods used were Method 5 for PM, Method 6C for SO_2, Method 7E for NO_x, Method 10 for CO, Method 25A for TOC, and Orsat for CO_2. The methods used to test for HCl and VOC were not specified in the document. Three runs were conducted during each of the three tests. Emission factors were developed for filterable PM, SO_2, NO_x, CO, CO_2, TOC, VOC, and HCl emissions from the kiln.

The PM, SO_2, NO_x, CO, CO_2, and TOC emission data are rated B. Although standard test methods were used, the document lacked adequate information to warrant a higher rating. The HCl and VOC data are rated D because the test method is not specified.

4.2.1.50 Reference 55. This report documents measurements of filterable PM, condensible inorganic PM, SO_2, SO_3, NO_x, and CO_2 from a preheater process coal-fired rotary kiln. The purpose of the test was to demonstrate compliance with State regulations. The test was conducted in 1983. Process rates were provided on the basis of the kiln feed and clinker production rates. The sulfur content of the coal was reported as 0.48 percent. Emissions from the kiln are controlled with a fabric filter.

Method 5 was used to measure PM emissions. Emissions of SO_2 and SO_3 were quantified by analyzing the back half of the PM sampling train. The back half of the sampling train included an impinger containing 80 percent isopropyl alcohol to absorb sulfur trioxide; and an impinger containing a 6 percent solution of hydrogen peroxide to absorb SO_2. Method 7 was used to measure NO_x emissions. The method used to measure CO_2 concentrations was not specified. Three test runs were conducted. Emission factors were developed for controlled filterable and inorganic condensible PM, SO_2, SO_3, CO_2, and NO_x emissions.

The PM, NO_x, and CO_2 data are rated B. The methodology was sound, but the documentation was not in adequate detail to warrant a higher rating. The emission data for CO_2 are rated C because the test method was not specified. The emission data for SO_2 and SO_3 are rated C due to the lack of adequate documentation and the nonstandard test methods used.

4.2.1.51 Reference 56. This reference consists of selected pages from a report that documents an emission test on a coal-fired preheater/precalciner kiln. Measurements were made of emissions of filterable PM, condensible inorganic PM, SO_2, NO_x, and CO_2 from the main kiln stack and the alkali bypass stack. The test was conducted in 1980 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed and clinker production rate. Emissions from the kiln are controlled with a fabric filter.

The test methods used to measure emissions were not specified in the reference. Three runs were conducted during each of the three tests. Emission factors were developed for filterable PM, condensible inorganic PM, SO_2, NO_x, and CO_2 emissions from the kiln.

The PM, SO_2, NO_x, and CO_2 emission data are rated D because the test methods were not specified, and the reference lacked other details on the testing and process.

4.2.1.52 Reference 57. This reference consists of summary data from seven compliance tests on a preheater/precalciner kiln between 1983 and 1989. Data on emissions of PM, SO_4^{-2}, SO_2, NO_x, CO, and TOC are included. Coal was burned during three of the tests; a combination of gas and coal was burned during three of the tests; and a combination of gas, coal, and oil was burned during the remaining

test. Average clinker production rates were provided for each of the tests. Kiln emissions are controlled by means of a fabric filter, and only controlled emissions were measured.

Methods 5 and 8 were used to measure PM and SO_2; CARB Method 1-100 was used to measure NO_x and CO; and TOC emissions were quantified used GC-FID. Three runs were conducted during each test. Emission factors were developed for filterable PM, SO_4^{-2}, SO_2, NO_x, CO, and TOC emissions.

Due to a lack of documentation, all of the emission data from this reference are rated C.

4.2.1.53 Reference 58. This report documents measurements of filterable PM and SO_2 from a coal-fired preheater/precalciner kiln. The test was conducted in 1981 to demonstrate compliance with State regulations. Process rates were provided on the basis of the kiln feed rate. Emissions from the kiln are controlled with an ESP.

Method 5 was used to measure PM emissions. However, the PM data were missing from the report. Emissions of SO_2 were quantified using Method 6, and three test runs were conducted. Emission factors were developed for controlled SO_2 emissions.

The SO_2 emission data are rated B. The methodology was sound, and no problems were reported. However, the report lacked adequate documentation to warrant a higher rating.

4.2.1.54 Reference 59. This reference includes selected pages from a report documenting measurements of SO_2 from a coal-fired preheater/precalciner kiln. The test was conducted in 1983, and the purpose was to determine the effect of a PM emissions control device on SO_2 emissions. Process rates were provided on the basis of the clinker production rate.

Emissions from the kiln pass through a spray tower, and then through an ESP. Concentrations of SO_2 were measured before and after the ESP using a CEM over a 3-day period. However, the emission rates were determined using the average SO_2 concentration and a single volumetric flow rate measurement. Emission factors were developed for SO_2 emissions before and after the ESP. The SO_2 emission data are rated C because they are based on a single volumetric flow measurement.

4.2.1.55 Reference 60. This report documents an emission test on a coal-fired preheater/precalciner kiln. The kiln tested is the same kiln for which an emission test was documented in Reference 56. Measurements were made of emissions of filterable PM, condensible inorganic PM, NO_x, and CO_2 from the main kiln stack and the alkali bypass stack. The test was conducted in 1984 to demonstrate compliance with State regulations. Process rates were provided on the basis of kiln feed. Emissions from the kiln are controlled with a fabric filter.

Method 5 was used to measure PM emissions, and Method 7 was used to measure emissions of NO_x. Concentrations of CO_2 were measured using Orsat. Three runs were conducted on each of the kiln sources. However, the final test run was not completed due to a kiln shutdown. Emission factors were developed for filterable PM, condensible inorganic PM, NO_x, and CO_2 emissions from the kiln (main stack and alkali bypass stack combined).

The NO_x and CO_2 emission data are rated C. Although the test methodologies were sound, only two test runs were completed. The PM data are rated B. Although the methodologies were sound, the report lacked adequate documentation to warrant a higher rating.

4.2.1.56 Reference 61. This report documents emission tests on a coal-fired preheater/precalciner kiln, clinker cooler, raw mill, and finish mill. Measurements were made of emissions of filterable PM, SO_2, NO_x, CO, TOC and CO_2 from the kiln. The clinker cooler, raw mill, and finish mill were tested for PM emissions. The tests were conducted in 1985 to evaluate the performance of newly installed equipment. Process rates were provided on the basis of kiln feed.

Emissions from the kiln and mills are controlled with separate fabric filters, and emissions from the clinker cooler are controlled with a gravel filter bed. Method 5 was used to measure PM emissions, and CEM's were used in accordance with CARB Method 1-100 to measure emission concentrations of SO_2, NO_x, CO, TOC, and CO_2.

Three runs were conducted on each of the four sources. Emission factors were developed for filterable PM, SO_2, NO_x, CO, TOC, and CO_2 emissions. The results of Run 1 on the clinker cooler PM test are suspect due to contamination of the sampling train probe. Therefore, the clinker cooler emission factor is based only on Runs 2 and 3.

With the exception of the clinker cooler test, the emission data are rated B. The methodology was sound and no problems were noted, but the report lacked adequate documentation to warrant a higher rating. The clinker cooler PM emission data are rated C because only two of the test runs were valid.

4.2.1.57 Reference 62. This report documents emission tests on a coal-fired preheater/precalciner kiln, raw mill, raw mill feed belt, finish mill, and finish mill feed belt. Measurements were made of emissions of filterable PM, SO_2, NO_x, CO, and CO_2 from the kiln. The raw mill, raw mill feed belt, finish mill, and finish mill feed belt were tested for PM emissions. The tests were conducted in 1985 to evaluate the performance of newly installed equipment. The kiln, raw mill, and finish mill are the same as those for which emission measurements were documented in Reference 61. Process rates were provided on the basis of kiln feed and production.

Emissions from the kiln, mills, and mill feed belts are controlled with separate fabric filters. Method 5 was used to measure PM emissions, and CEM's were used in accordance with CARB Method 1-100 to measure emission concentrations of SO_2, NO_x, CO, and CO_2. Three runs were conducted on each of the four sources. Emission factors were developed for filterable PM, SO_2, NO_x, CO, and CO_2 emissions.

With the exception of the raw mill feed belt data, the emission data are rated B. The methodology was sound and no problems were noted, but the report lacked adequate documentation to warrant a higher rating. The raw mill feed belt data are rated C because only two test runs were conducted.

4.2.1.58 Reference 63. This report documents an emission test on a coal-fired preheater/precalciner kiln. Measurements were made of emissions of filterable PM, SO_2, NO_x, CO, and CO_2 from the kiln. The tests were conducted in 1987 to demonstrate compliance with State regulations.

The kiln is the same one for which emission measurements were documented in References 61 and 62. Process rates were provided on the basis of kiln feed rates.

Emissions from the kiln are controlled with a fabric filter. Method 5 was used to measure PM emissions, and CEM's were used in accordance with CARB Method 1-100 to measure emission concentrations of SO_2, NO_x, CO, and CO_2. Three runs were conducted on each of the four sources. Emission factors were developed for filterable PM, SO_2, NO_x, CO, and CO_2 emissions.

The emission data are rated B. The methodology was sound and no problems were noted, but the report lacked adequate documentation to warrant a higher rating.

4.2.1.59 Reference 64. This report documents an emission test on a coal-fired preheater/precalciner kiln. Measurements were made of emissions of filterable PM, SO_2, NO_x, CO, CO_2, NH_3, and HCl from the kiln. The tests were conducted in 1987 to demonstrate compliance with State regulations and to determine NH_3 and HCl emission rates. Emissions from the kiln are controlled with a fabric filter. The kiln is the same one for which emission measurements were documented in References 61, 62, and 63. Process rates were provided on the basis of kiln feed rates.

Method 5 was used to measure PM emissions. Continuous monitors were used in accordance with CARB Method 1-100 to measure emission concentrations of NO_x, CO, and CO_2. Emissions of SO_2 were quantified using Method 8, and NH_3 and HCl emissions were measured using modified Method 5 sampling trains. To test for NH_3, the Method 5 train was modified to include two impingers (impingers 1 and 2) containing 100 milliliters (ml) of 0.1 normal (N) HCl. In the HCl test, the Method 5 train was modified to include two impingers (impingers 1 and 2) containing 100 ml of 0.1 N sodium hydroxide.

Three runs of each of the sampling trains were conducted. In general, the tests were completed without a problem. However, the calibration sheets indicated a consistent problem in calibrating the CEM for CO. Emission factors were developed for filterable PM, SO_2, NO_x, CO, CO_2, NH_3, and HCl emissions.

The emission data for PM, SO_2, NO_x, TOC, HCl, and CO_2 are rated B. The methodology was sound and no problems were noted, but the report lacked adequate documentation to warrant a higher rating. The CO emission data are rated D because of the problems in calibrating the CEM for CO. The NH_3 data are rated D because the method used was inappropriate.

4.2.1.60 Reference 65. This report documents emissions from a wet process kiln cofired with waste fuels and coal. The test, which was sponsored by EPA's Office of Solid Waste, was conducted to compare emissions from the kiln during cofiring to those generated at baseline when only fossil fuels were fired. The test was conducted in 1990.

The kiln is operated with a clinker capacity of about 1,700 Mg/day (1,870 tons/day) and fires a combination of coal and liquid waste fuels, which typically consist of a combination of waste solvents and thinners. Emissions from the kiln are controlled by a mechanical collector and a four-field ESP in series. A series of tests, sponsored by EPA, was conducted at the ESP exhaust to compare emissions under different fuel-firing scenarios. Originally, the protocol called for two scenarios--coal-only baseline and coal/liquid waste cofiring. However, the system could not maintain stable operations during the coal-only baseline run, which makes results from this single run suspect. Consequently, the final test sequence

included a coal-only baseline (1 run), a coal/diesel fuel baseline (2 runs), and the coal/liquid waste condition (3 runs). The purpose of the coal/diesel baseline runs was to overcome the problems associated with the coal only baseline run by simulating the plant's standard firing condition of coal and liquid waste firing with coal and a liquid fossil fuel (diesel).

The test protocol called for quantitation of a variety of criteria and noncriteria pollutants. Criteria pollutants measured were CO (Method 10) and TNMOC (Method 25). Noncriteria pollutant measurements included CO_2 (by CEM), semivolatile organic compounds (Method 010), VOC (VOST-Method 030), and HCl (Modified Method 5). Emission factors were developed from the results of the baseline run (coal only). These baseline data are unrated because only one test run was conducted and the process was not operating normally during the run.

Emission factors were not developed from the data from the coal/diesel runs because this combination of fuels is not representative of the plant's standard operating practice; emission factors were not developed from the coal- and liquid waste fuel-fired runs because the emission characteristics would likely be a function of the amount and chemical constituents of liquid waste used, and therefore may not be of use in estimating emissions from other kilns in the industry.

4.2.1.61 Reference 66. This report documents emissions from a preheater/precalciner process kiln cofiring waste fuels and coal. The test, which was sponsored by EPA's Office of Solid Waste, was conducted to compare emissions from the kiln during cofiring to those generated at baseline when only fossil fuels were fired. The test was conducted in 1990.

The kiln is operated with a clinker capacity of about 1,640 Mg/d (1,800 tons/d). The system typically fires a combination of fossil fuels (coal, natural gas, or No. 2 fuel oil) and liquid organic waste to the kiln and a combination of pulverized coal and liquid or solid organic waste in the pyroclone precalciner. The exhaust gases from both the main kiln stack and the alkali bypass stack are exhausted through ESP's to the atmosphere. This series of tests, which was sponsored by EPA, measured emissions from both the main kiln stack and the alkali by-pass stack. Because the test sequence was designed to compare emissions from fossil fuel and waste firing, emissions were measured under three operating conditions--coal only (1 run), liquid waste only (2 runs), and a coal/liquid waste mixture(2 runs)--fired to the kiln. During all conditions pulverized coal was fired to the pyroclone precalciner.

The test protocol involved quantitation of a range of criteria and noncriteria pollutants. Criteria pollutants measured included CO (Method 10), TOC (Method 25A) and SO_2 and NO_x with plant CEM monitors. Noncriteria pollutant measurements included CO_2 (by CEM), VOC organic screen (VOST-Method 030), a semivolatile organic screen method (Method 030) that included quantitation of chlorinated dibenzo-p-dioxins and chlorinated dibenzofurans (CDD/CDF), and HCl (MM5). Both organic sampling methods are integrated extractive sampling procedures with analysis by GC/MS.

Emission factors were developed from the results of the baseline run (coal only). These baseline data are unrated because only one test run was conducted. Emission factors were not developed from the waste fuel-fired runs because the emission characteristics would likely be a function of the amount and chemical constituents of waste used, and therefore may not be of use in estimating emissions from other kilns in the industry.

4.2.1.62 Reference 67. This report documents measurements of filterable PM and CO_2 from a wet process coal-fired rotary kiln. The emission test was conducted in 1980 to demonstrate compliance with State regulations. The kiln tested is the same kiln emissions of which are documented in Reference 29. Process rates were provided as the total dry kiln feed and insufflated dust feed rate.

Emissions from the kiln are controlled with an ESP, and only controlled emissions were measured. Emissions of filterable PM were measured using Method 5, and CO_2 emissions were quantified by Orsat. Three runs of PM were conducted. Emission factors were developed for filterable PM and CO_2 emissions from the kiln.

The emission data are rated C. Although the test methodology was sound, the report does not include a process description and generally is lacking in details.

4.2.1.63 Reference 68. This report documents measurements of filterable PM from a clinker cooler. The emission test was conducted at the same facility simultaneously with the kiln emission test that is documented in Reference 67. The purpose of the test was to demonstrate compliance with State regulations. Process rates were provided on the basis of clinker cooler feed rate. However, the clinker cooler feed rate reported is identical to the kiln feed rate reported in Reference 67 for the same test period. For this reason, it appears that the cooler feed rate is incorrect, and emission factors were not developed from this report.

4.2.1.64 Reference 69. This report documents measurements of PM and CO_2 from three dry process coal-fired rotary kilns. The kilns are equipped with suspension preheaters. The emission test were conducted in 1979 to determine differences in emission rates for the same kilns fueled with natural gas. Process rates were provided on the basis of kiln feed rates and included raw material and insufflated dust feed rates.

The kilns are equipped with fabric filters to control emissions, and only controlled emissions were reported. Emissions of PM were measured using Hi-Vol samplers positioned in three of the six fabric filter compartments. Concentrations of CO_2 were measured by Orsat. Three test runs were conducted on kilns 1 and 3, and two test runs were conducted on kiln 2. Emission factors were developed for filterable PM and CO_2 emissions.

The PM emission data are rated C because of problems reported in calibrating the Hi-Vol samplers. The CO_2 data for kilns 1 and 3 are rated B. The test methodology was sound, and no problems were reported. However, the documentation was inadequate to warrant a higher rating. The CO_2 data for kiln 2 are rated C because only two runs were conducted.

4.2.1.65 Reference 70. This report documents a determination of visible emissions from kilns at four portland cement plants. Because the report does not contain emission data, it could not be used to develop emission factors.

4.2.1.66 Reference 71. This report documents measurements of filterable PM, NO_x, and SO_2 from a kiln and emissions of filterable PM from a clinker cooler. The emission test was conducted in 1983 to demonstrate compliance with State regulations. The report does not specify the type of kiln or control device tested. In addition, clinker cooler feed rates are not provided. For these reasons, emission factors were not developed from the report.

4.2.1.67 Reference 72. This report documents measurements of filterable PM from a dry process rotary kiln fired with coal. The emission test was conducted in 1983 to demonstrate compliance with State regulations. Emissions from the kiln are controlled with a combination of an ESP and a series of fabric filters in parallel. Emission factors were not developed from the report because of the atypical control device configuration.

4.2.1.68 Reference 73. This report documents measurements of filterable PM, NO_x, and SO_2 from a kiln and emissions of filterable PM from a clinker cooler. The emission test was conducted in 1982 to demonstrate compliance with State regulations. The facility is the same plant for which emission measurements were documented in Reference 71. The report does not specify the type of kiln or control device tested. In addition, clinker cooler feed rates are not provided. For these reasons, emission factors were not developed from the report.

4.2.1.69 Reference 74. This report documents measurements of emissions from a coal-fired preheater/precalciner process kiln. The test was conducted to satisfy the requirements of AB 2588 ("Hot Spots") of the State of California and included measurements of dioxins and furans, polycyclic aromatic hydrocarbons (PAH), multiple metals, hexavalent chromium (Cr^{+6}) and total Cr, formaldehyde, HCl, and benzene, and CO_2. Process rates were provided on the basis of the kiln feed.

Emissions from the kiln are first ducted to the raw and coal mills and then to a 32-compartment fabric filter. However, the test was conducted with the raw mill not operating. Emissions were measured in only one stack (of 32, apparently) of the fabric filter. Although not specified in the reference, it assumed that the fabric filter had multiple stacks because the filter was a positive pressure type.

Emissions of dioxins and furans were measured using a modified Method 5, as described in CARB Method 428; PAH emissions were measured using CARB Method 429; emissions of multiple metals were quantified with EPA Method 0012; Cr^{+6} and total Cr emissions were measured using CARB Method 425; formaldehyde emissions were quantified with CARB Method 430; Emissions of HCl were measured using CARB Method 421; and benzene emissions were quantified with CARB Method 410. Three runs were conducted with each sampling train.

Emission factors were developed for six metals, heptachlorinated dibenzo-p-dioxin (HpCDD), octochlorinated dibenzo-p-dioxin (OCDD), pentachlorinated dibenzo-p-dioxin (PCDD), tetrachlorinated dibenzo-furan (TCDF), pentachlorinated dibenzo-furan (PCDF), HCl, CO_2, and 18 organic pollutants. Because emissions were sampled from only 1 of 32 stacks, emission rates were multiplied by 32 when developing emission factors from the test data.

The emission data are rated D because only 1 of 32 fabric filter stacks were sampled and total emissions had to be extrapolated over the entire fabric filter in order to develop emission factors from the data.

4.2.1.70 Reference 75. This reference consists of selected pages of a test report that documents emissions from a preheater/precalciner rotary kiln. The purpose of the tests was to determine the effects on emission characteristics of burning tire chips as a supplemental fuel. A portion of the exhaust stream from the kiln is ducted to a raw mill prior to the air pollution control device. However, the control device is not specified.

The tests were conducted under four conditions: (1) burning coal with the raw mill on (three runs); (2) burning coal with the raw mill off (one run); (3) burning coal and tire chips with the raw mill off (one run); and (4) burning coal and tire chips with the raw mill on (three runs). Run-by-run data are provided for conditions 1 and 4 only. The data were not used to develop emission factors because the control device is not specified and emissions measured with the raw mill operating are of little use without information on the percentage of exhaust gas ducted to the raw mill.

4.2.1.71 Reference 76. This report documents emission tests on a coal- and waste fuel-fired preheater/precalciner rotary kiln. Emissions from the kiln are controlled with a fabric filter. The tests were conducted to satisfy the requirements of the BIF regulations. Three baseline runs (Phase I) were conducted during which the kiln was fired with coal only, and three runs (Phase II) were conducted during which the kiln was fired with a combination of coal, tires, and solid and liquid hazardous waste.

Emissions were sampled for filterable PM (Method 5), HCl and chlorine (Cl) (Method 0050), multiple metals (Method 0012), semivolatile organic compounds (Method 0010), VOC (Method 0030), CO (Method 10), CO_2 (Method 3A), and TOC (Method 25A). Three runs were conducted during both phases (baseline and hazardous waste cofiring) of testing, and no problems were reported. The baseline Method 0030 samples were analyzed for perchloroethylene, trichlorofluoromethane, 1,1,2 trichloroethane, and 1,1,1 trichloroethane, all of which were below the detection limit.

Emission factors were developed, from the baseline data only, for emissions of filterable PM, Cl, HCl, CO, CO_2, TOC, and 11 metals. The emission data are rated A. Emission factors were not developed from the coal- and waste fuel-fired runs because the emission characteristics would likely be a function of the amount and chemical constituents of waste used, and therefore may not be of use in estimating emissions from other kilns in the industry.

4.2.1.72 Reference 77. This report documents emission tests on two wet process rotary kilns (Nos. 1 and 2) that are ducted to a common ESP. The tests were conducted to satisfy the requirements of the BIF regulations for using hazardous waste as a supplemental fuel. The kilns were tested under two operating conditions. For condition I, kiln 1 was fired with coal and oil, and kiln 2 was fired with coal and tires. For condition II, kiln 1 was fired with coal and oil, and kiln 2 was fired with coal only. Three runs were conducted for each operating condition.

Emissions were sampled for filterable PM (Method 5), multiple metals (Method 0012), semivolatile organic compounds (Method 0010), dioxins and furans, VOC (Method 0030), SO_2 (Method 6), NO_x (Method 7E), CO (Method 10), CO_2 (Method 3A), and TOC (Method 25A).and no problems were reported. Emissions of seven metals and 15 organic compounds were found to be above the detection limit.

Only the baseline (condition II) data were used to develop emission factors. Emission factors were developed for emissions of filterable PM, condensible inorganic PM, SO_2, NO_x, CO, CO_2, TOC, 7 metals, and 15 organic compounds. The emission data are rated B. The methodologies were sound, and no problems were reported. However, the report lacked adequate documentation to warrant a higher rating.

4.2.1.73 Reference 78. This report documents emission tests on a coal-fired dry process rotary kiln. The tests were sponsored by EPA in order to determine the destruction and removal efficiency of

several inorganic and inorganic pollutants in kilns burning hazardous waste. The kilns were tested under two operating conditions: two baseline runs were conducted during which the kiln was fired with coal only, and three runs were conducted during which the kiln was fired with a combination of coal and waste fuel. Emissions from the kiln are controlled with an ESP. However, the ESP was malfunctioning during the entire test period.

Emissions were sampled for filterable PM (Method 5), HCl using the Method 6 midget impinger train, semivolatile organic compounds (modified Method 5), VOC (Method 0030), SO_2 (Method 6C), NO_x (Method 7E), CO (Method 10), CO_2 (Method 3A), and TOC (Method 25A). In addition, the Method 5 PM catch was analyzed for multiple metals using atomic absorption and inductively coupled argon plasma techniques. Because of the problem with the ESP, the PM, metals, and semivolatile organic compound data are highly suspect.

Only the baseline (condition II) data were used to develop emission factors. Emission factors were developed for emissions of filterable PM, SO_2, NO_x, CO, CO_2, TOC, HCl, 12 metals, and 5 VOC, and 9 semivolatile organic compounds.

The emission data for PM, metals and semivolatile organic compounds are rated D because only two runs were conducted and the control device malfunctioned during the tests. The emission data for 1,1,1 trichloroethylene are unrated because the concentrations measured were above the detection limit for only one run. The emission data for the other four VOC are rated C because only two test runs were conducted.

4.2.1.74 Reference 79. This reference is the background report for the 1986 revisions to the PM emission factors for AP-42 Section 11.6. With the exception of a few references that could not be located for this revision to Section 11.6, the references used in the preparation of Reference 79 also were reviewed and described in this background report. As explained in Section 4.2 of this report, the average particle size distribution data presented in Reference 79 were retained in the proposed revision to AP-42 Section 11.6 without change. These data are presented in Table 4-8. In addition, these particle size data were used to develop average PM-10 emission factors from the average PM emission factors developed for the proposed revision to the section.

4.2.1.75 Reference 80. This secondary reference provides a theoretical and empirical evaluation of metal and organic compound emissions from portland cement kilns firing both traditional fossil fuels and waste derived fuel including both hazardous waste and waste tires. The study focuses on three major issues--the partitioning of metal compounds in the various kiln discharge streams, the destruction and removal efficiency of the hazardous organic constituents in the waste fuels, and the formation of organic products of incomplete combustion for both conventional fossil fuels and waste-derived fuels. All emission data presented in the report were secondary data, and little information was provided on either the sampling and analysis methodology used to generate the data or the processes tested. In particular, no process operating rates were presented for any of the kilns during the test period. Consequently, emission factors could not be calculated from the data presented.

While emission factors were not generated from the report, several findings from this study may be useful for analyses of metal and organic compound data from portland cement kilns. First, this study found that metal compounds could be grouped into three general classes--volatile metals (Hg and Tl), semivolatile metals (Sb, Cd, Pb, Se, Zn, K, and Na), and refractory or nonvolatile metals (Ba, Be, Cr, As

[which acts as a refractory metal even though it is relatively volatile because it tends to form arsenates in the kiln], Ni, V, Mn, Cu, and Ag). Although the partitioning of these groups is affected by kiln operating conditions, the refractory metals tend to concentrate in the clinker, while the volatile and semivolatile metals tend to be discharged via the primary exhaust stack and the by-pass stack, respectively. Details on the partitioning of the different metals and the effects of operating parameters on this partitioning are supplied in the report. Relative to organic constituents, the study indicated that the formation of chlorinated dibenzo-p-dioxins, chlorinated dibenzofurans, and other chlorinated compounds, particularly chlorinated benzenes, appeared to be related to the chlorine content of waste fuels. However, the data presented in the report were insufficient to quantify the relationship.

4.2.2 Estimate of Theoretical CO_2 Emission Factors for Portland Cement Kilns[81]

Carbon dioxide is emitted from portland cement manufacturing kilns by two mechanisms: the reduction of carbonate (CO_3^{-2}) in the feed material to CaO and the oxidation of carbon in the fuel. Portland cement typically contains the equivalent of 63.5 percent CaO, which corresponds to the release of approximately 500 kg of CO_2 per Mg (1,000 lb/ton) of cement produced. The amount of CO_2 released as a result of the second mechanism depends on the energy efficiency of the kiln and the type of fuel used. The fuel required produce to 1 Mg (1 ton) of portland cement is estimated to be 5.42×10^9 joules (j) (5.14 million British thermal units [MMBtu]) for wet process kilns, 5.09×10^9 j (4.82 MMBtu) for dry process kilns, and 3.85×10^9 j (3.65 MMBtu) for preheater kilns. Fuel requirements for preheater/precalciner kilns were not available. However, because of increased efficiency, preheater/precalciner kilns should have lower energy requirements than preheater kilns.

Using a CO_2 emission factor of 0.100 kg/j (233 lb/Btu) for coal and 0.603 kg/j (140 lb/MMBtu) for gas, the emission factors for CO_2 emissions from fuel combustion can be estimated in units of mass of cement produced. The CO_2 emission factor for both mechanisms can be combined to yield estimates of the total CO_2 emission factors for portland cement kilns. These estimated emission factors are presented in Table 4-10.

4.2.3 Review of XATEF and SPECIATE Data Base Emission Factors

The XATEF data base contains emission factors for manganese, nickel, beryllium, cadmium, and chromium for most of the portland cement manufacturing PM sources described earlier. However, when the emission factors were traced back to the original reference, they were found to be based on the application of a fraction of metal in dry cement dust to earlier AP-42 emission factors. No actual emission data were referenced. Consequently, these emission factors do not satisfy the minimum criteria for inclusion in AP-42.

The SPECIATE data base also includes emission factors for most portland cement plant PM sources. The SPECIATE documentation notes that two sets of factors are based on cement kiln emission tests and the others are based on unknown methods. To date, the original references for the test data have not been obtained, so the emission factors do not meet minimum criteria for inclusion in AP-42. However, the references are being pursued, and additional metals emission factors may be included in a subsequent draft.

4.2.4 Review of Background File

The references reviewed for this revision included all test reports and relevant information included in the AP-42 background file for portland cement manufacturing. These references are described in Section 4.2.1. of this report.

4.2.5 Results of Data Analysis

This section discusses the analysis of the data and describes how the data were used to develop average emission factors for portland cement manufacturing. These average emission factors are listed in Tables 4-11 to 4-17. As described in Section 4.2, emission factors for kilns are presented in units of mass of pollutant emitted per mass of clinker produced.Emission factors for clinker coolers and other sources are presented in units of mass of pollutant emitted per mass of material processed. The following paragraphs describe how the emission data from individual test reports were used to develop the average emission factors for portland cement manufacturing. Emission factors for emissions of criteria pollutants (PM, PM-10, SO_2, NO_x, CO, and VOC's) and CO_2 from portland cement kilns are discussed in the following order: wet process kilns, long dry process kilns, dry preheater process kilns, and dry preheater/precalciner process kilns. Following the discussions of specific types of kilns, general emission factors for emissions of other pollutants (metals, other inorganics, and organics) from portland cement kilns are discussed. Finally, emission factors for emissions from clinker coolers and other portland cement manufacturing processes are discussed.

The emission factor ratings assigned to each of the average emission factors developed for portland cement manufacturing are based on the emission data ratings and the number of tests conducted. Of the 553 data sets from which emission factors were developed, 21 were A-rated, 180 were B-rated, 112 were C-rated, 109 were D-rated, and 131 were unrated. In general, A- and B-rated data are not supposed to be averaged with C- and D-rated data. However, because of the relatively large number of C-rated data sets reviewed, emission factors based on C-rated data were averaged with B-rated data if no A-rated data were available for that particular combination of source, control, and pollutant, and the number of C-rated tests were relatively large in comparison to the number of B-rated tests. D-rated data were used only when A- or B-rated data were not available.

A number of the references described in Section 4.2.1 document multiple emission tests on the same kiln. In such cases, the emission factors based on the results of all of the emission tests on the same kiln were averaged first. For these average emission factors, data ratings were assigned as follows. If the data from the individual tests were assigned the same rating, the average data set for that kiln was assigned that rating. If the data from the individual tests were assigned two different ratings, the average data set was assigned the higher of the two ratings if there were at least as many individual data sets rated at the higher rating than individual data sets rated at the lower rating. For example, if there were four tests conducted on the same kiln, two (or more) were rated B, and two (or less) were rated C, the average data set for the kiln was assigned a rating of B. If one B-rated tests and three C-rated tests were obtained for the same kiln, the average data set was assigned a rating of C. With few exceptions the individual tests on the same kiln were rated B or C. In a few cases, individual D-rated data sets were combined with C-rated data sets. After the average kiln emission factors were determined, they were combined with the emission factors developed for other kilns as described previously in this section and in Sections 3.2 and 3.3 of this report. Appendix A provides additional information on how the emission factors were derived for criteria pollutant emissions from portland cement kilns.

4.2.5.1 Wet Process Kilns. Of the 81 data sets from which emission factors were developed for criteria pollutant emissions from wet process kilns, none were rated A, 33 were rated B, 35 were rated C, 6 were rated D, and 7 were not rated. The majority of the tests documented were conducted on coal-fired wet process kilns. However, some data were available on emissions from gas- and oil-fired wet process kilns, and one test report documented emissions from a wet process kiln fired with a combination

of coal and oil. For kilns fired with fuels other than coal, the number of documented tests were so few that emission factors developed from the data are not likely to be representative of emissions from kilns using alternatives to coal as fuel. Therefore, the data from kilns fired with gas and oil were combined with the coal-fired kiln emission data. The average criteria pollutant emission factors developed for wet process kilns are summarized in Table 4-11. The following paragraphs describe how these average emission factors for wet process kilns were developed.

Filterable PM. For uncontrolled emissions of filterable PM from wet process kilns, data from two B-rated, one C-rated, and one D-rated test were available. The emission factor developed from the B-rated tests averaged 65 kg/Mg (130 lb/ton), the emission factor developed from the C-rated test averaged 180 kg/Mg (350 lb/ton), and the emission factor developed from the D-rated data averaged 630 kg/Mg (1,300 lb/ton). The C- and D-rated data were discarded, and the B-rated data were used for the average emission factor for uncontrolled filterable PM emissions from wet process kilns. This emission factor is rated D.

For filterable PM emissions controlled with an ESP, a total of 20 data sets were available. After combining the results of multiple tests on the same kiln, the number of data sets was reduced to 11. Five of these data sets were rated B, and six of the data sets were rated C. The emission factors developed from the B-rated data ranged from 0.13 kg/Mg (0.25 lb/ton) to 0.60 kg/Mg (1.2 lb/ton) and averaged 0.38 kg/Mg (0.76 lb/ton). The emission factors developed from the C-rated data ranged from 0.069 kg/Mg (0.14 lb/ton) to 1.0 kg/Mg (2.0 lb/ton) and averaged 0.39 (0.77 lb/ton). The B- and C-rated data were combined for an average emission factor for ESP-controlled filterable PM emissions from coal-fired wet process kilns of 0.38 kg/Mg (0.77 lb/ton). This average emission factor is assigned a rating of C.

A single test was available on emissions from a coal-fired wet process kiln controlled with a combination of cooling tower, multiclone, and ESP. The data from this test were rated C, and were used to develop an E-rated emission factor of 0.10 kg/Mg (0.20 lb/ton).

For fabric filter-controlled filterable emissions from a coal-fired wet process kiln, data from one C-rated and one unrated test were available. The data from the C-rated test yielded an E-rated emission factor of 0.23 kg/Mg (0.46 lb/ton).

Emission factors for filterable PM-10 emissions from uncontrolled wet process kilns, and ESP-controlled wet process kilns also were developed by multiplying the cumulative mass percent less than 10 Fm presented in Reference 79 by the average emission factors described in the preceding paragraphs.

Condensible inorganic PM. For condensible inorganic PM emissions from wet process kilns, data from eight emission tests were available: two B- and two C-rated tests on ESP-controlled kilns, one C-rated and two unrated tests on fabric filter-controlled kilns, and a C-rated test on a kiln controlled with a combination of cooling tower, multiclone, and ESP. For ESP-controlled condensible inorganic PM emissions, emission factors developed from B-rated data were 0.11 kg/Mg (0.21 lb/ton) and 0.024 kg/Mg (0.047 lb/ton), and emission factors developed from the C-rated data were 0.10 kg/Mg (0.20 lb/ton) and 0.075 kg/Mg (0.15 lb/ton). The B- and C-rated data were combined to yield an average emission factor of 0.076 kg/Mg (0.15 lb/ton) for condensible inorganic PM emissions from an ESP-controlled wet process kiln. For fabric filter-controlled condensible inorganic PM emissions, an E-rated emission factor of 0.10 kg/Mg (0.20 lb/ton) was developed from the C-rated test data, and for condensible inorganic

emissions controlled with a combination of cooling tower, multiclone, and ESP, an E-rated emission factor of 0.14 kg/Mg (0.29 lb/ton) was developed.

Sulfur dioxide. For SO_2 emissions from wet process kilns, a total of 22 data sets were available. Two of the data sets consists of measurements of SO_2 emissions prior to a control device, 17 tests were conducted on ESP-controlled kilns, and 3 tests were conducted on fabric filter-controlled kilns. Because ESP's are expected to have negligible effects on SO_2 emissions, the ESP-controlled kiln data sets were treated as measurements of uncontrolled SO_2 emissions. Fabric filters also are considered to have negligible effects on SO_2 emissions, and the emission factors developed from the fabric filter-controlled kiln tests were comparable in magnitude to the emission factors developed from the other test data. Therefore, the results of the fabric filter-controlled tests also were treated as measurements of uncontrolled SO_2 emissions. After combining the results of multiple tests on the same kiln, the number of data sets was reduced to 13. Four of these data sets were rated B, four of the data sets were rated C, three of the data sets were rated D, and two data sets were unrated. The emission factors developed from the B-rated data ranged from 1.2 kg/Mg (2.3 lb/ton) to 8.3 kg/Mg (17 lb/ton) and averaged 4.7 kg/Mg (9.5 lb/ton). The emission factors developed from the C-rated data ranged from 1.9 kg/Mg (3.8 lb/ton) to 5.2 kg/Mg (10 lb/ton) and averaged 3.6 kg/Mg (7.0 lb/ton). The D- and unrated data were discarded, and the B- and C-rated data were combined for an average emission factor for uncontrolled SO_2 emissions from wet process kilns of 4.1 kg/Mg (8.2 lb/ton). This average emission factor is assigned a rating of C.

Nitrogen oxides. For NO_x emissions from wet process kilns, a total of 12 data sets were available, 11 of which are from tests conducted on ESP-controlled kilns; the remaining data set is from a fabric filter-controlled kiln. Because ESP's and fabric filters are expected to have negligible effects on NO_x emissions, all data sets were treated as measurements of uncontrolled NO_x emissions. After combining the results of multiple tests on the same kiln, the number of data sets was reduced to nine. Five of these data sets were rated B, two data sets were rated C, one data set was rated D, and one data set was unrated. The emission factors developed from the B-rated data ranged from 1.7 kg/Mg (3.5 lb/ton) to 10 kg/Mg (20 lb/ton) and averaged 3.7 kg/Mg (7.4 lb/ton). The emission factors developed from the C-rated data were determined to be 3.3 kg/Mg (6.6 lb/ton) and 1.4 kg/Mg (2.9 lb/ton). The D-rated and unrated data were discarded. Because the number of C-rated tests was relatively small in comparison to the number of B-rated tests, the C-rated data were discarded and only the B-rated data were used. This average emission factor is assigned a rating of D.

Carbon monoxide. For CO emissions from wet process kilns, the only rated data available consist of the results of a single test on an ESP-controlled wet process kiln. Because ESP's are expected to have negligible effects on CO emissions, the data were treated as measurements of uncontrolled CO emissions. These data are rated B and were used to develop a D-rated emission factor of 0.060 kg/Mg (0.12 lb/ton).

Carbon dioxide. For CO_2 emissions from wet process kilns, a total of 14 data sets were available on measurements of CO_2 emissions from ESP-controlled kilns. Because ESP's are expected to have negligible effects on CO_2 emissions, all data sets were treated as measurements of uncontrolled CO_2 emissions. One of the tests was rated D and one of the tests was unrated; both of these data sets were discarded. After combining the results of multiple tests on the same kiln, the number of data sets were reduced to seven. Five of these data sets were rated B, and two of the data sets were rated C. The emission factors developed from the B-rated data ranged from 980 kg/Mg (2,000 lb/ton) to 1,500 kg/Mg (2,900 lb/ton) and averaged 1,200 kg/Mg (2,400 lb/ton). The emission factors developed from the C-rated

data were 570 kg/Mg (1,100 lb/ton) and 890 kg/Mg (1,800 lb/ton) and averaged 730 kg/Mg (1,500 lb/ton). Because the theoretical average emission factor for CO_2 emissions from wet process kilns as discussed in Section 4.2.2 is 1,100 kg/Mg (2,200 lb/ton), the B-rated data appear to be biased high. Therefore, the B- and C-rated data were combined for an average emission factor for uncontrolled CO_2 emissions from coal-fired wet process kilns of 1,100 kg/Mg (2,100 lb/ton). In comparison to the theoretical average emission factor for CO_2 emissions from coal-fired wet process kilns, the magnitude of this average emission factor appears to be reasonable. This average emission factor is assigned a rating of C.

Volatile Organic Compounds. For wet process kilns, data were available from one test of TOC emissions. The test was conducted on an ESP-controlled kiln. Because ESP's should have negligible effects on VOC emissions, the results were treated as uncontrolled emissions. The data were rated B, and the emission factor developed from the data is rated D.

4.2.5.2 Long Dry Process Kilns. Of the 46 data sets from which emission factors were developed for long dry process kiln emissions, 2 were rated A, 21 were rated B, 15 were rated C, 7 were rated D, and 1 was not rated. All of the tests documented were conducted on coal-fired dry process kilns. The average emission factors developed from these data sets are provided in Table 4-12. The following paragraphs describe how these average emission factors for long dry process kilns were developed.

Filterable PM. For filterable PM emissions from long dry process kilns controlled with an ESP, a total of three data sets were available. Two of these data sets were rated B, and one of the data sets was rated D. The D-rated data were discarded. Data were available from three tests conducted on emissions from a dry process kiln controlled with a combination of cooling tower, multiclone, and ESP. The data from all three tests were rated B, and ranged from 0.65 kg/Mg (1.3 lb/ton) to 0.85 kg/Mg (1.7 lb/ton). These emission factors for the five tests were combined to yield a D-rated average emission factor of 0.50 kg/Mg (1.0 lb/ton) for filterable PM emissions from an ESP-controlled dry process kiln.

For fabric filter-controlled filterable emissions from a dry process kiln, data from one A-rated test and two C-rated tests were available. The emission factors for the C-rated tests, which ranged from 0.046 kg/Mg (0.093 lb/ton) to 0.10 kg/Mg (0.19 lb/ton), were discarded. The A-rated data yielded a D-rated emission factor of 0.10 kg/Mg (0.20 lb/ton).

Emission factors for filterable PM-10 emissions from uncontrolled long dry process kilns, and fabric filter-controlled long dry process kilns were developed by multiplying the cumulative mass percent less than 10 Fm presented in Reference 79 by the average emission factors described in the preceding paragraphs.

Condensible inorganic PM. For condensible inorganic PM emissions from long dry process kilns, data from seven emission tests were available: two B-rated tests on ESP-controlled kilns; three B-rated tests on a kilns controlled with a combination of cooling tower, multiclone, and ESP; and one A-rated and one C-rated test on fabric filter-controlled kilns. Each of these data sets were used to develop an average emission factor. For ESP-controlled condensible inorganic PM emissions, the factors developed from the two tests were 0.13 kg/Mg (0.26 lb/ton) and 0.41 kg/Mg (0.82 lb/ton) and averaged 0.27 kg/Mg (0.54 lb/ton). For condensible inorganic emissions controlled with a combination of cooling tower, multiclone, and ESP, the emission factors developed from the three B-rated tests ranged from 0.11 kg/Mg (0.21 lb/ton) to 0.17 kg/Mg (0.33 lb/ton). The average for the five tests is 0.19 kg/Mg (0.38 lb/ton). This average emission factor is rated D.

For fabric filter-controlled condensible inorganic PM emissions, a D-rated emission factor of 0.45 kg/Mg (0.89 lb/ton) was developed was developed from the A-rated test data; the C-rated data were discarded.

Sulfur dioxide. For SO_2 emissions from long dry process kilns, a total of seven data sets were available. Two of the data sets consist of measurements of SO_2 emissions from ESP-controlled kilns, and the remaining five data sets consist of measurements of SO_2 emissions from fabric filter-controlled dry kilns. Because the average emission factor developed from the ESP-controlled emission tests is four times the average of the fabric filter-controlled kiln test emission factors, the data appear to indicate that ESP's and fabric filters affect SO_2 emissions differently. However, the fabric filter data all fall within the range of the ESP test data. In addition, both types of control devices are expected to have negligible effects on SO_2 emissions. Therefore, all data sets were treated as measurements of uncontrolled SO_2 emissions. Five of the data sets were rated B, one of the data sets was rated C, and two of the data sets were rated D. The D-rated data were discarded. The emission factor developed from the C-rated test was 0.046 kg/Mg (0.092 lb/ton). The emission factors developed from the B-rated tests ranged from 0.20 kg/Mg (0.40 lb/ton) to 14 kg/Mg (28 lb/ton) and averaged 4.9 kg/Mg (10 lb/ton). The C-rated data were discarded because there were substantially more B-rated data sets. The average emission factor developed from the B-rated data is rated D.

Nitrogen oxides. For NO_x emissions from long dry process kilns, nine data sets were available. Two of the tests were conducted on kilns with unspecified emission controls, one of the tests was conducted on an ESP-controlled kiln, and six of the tests were conducted on kilns controlled with fabric filters. Because ESP's and fabric filters are expected to have negligible effects on NO_x emissions, all data sets were treated as measurements of uncontrolled NO_x emissions. Three of these data sets were rated B, four of the data sets were rated C, and two of the data sets were rated D. The D-rated data were discarded. The emission factors developed from the B-rated data ranged from 2.2 kg/Mg (4.3 lb/ton) to 4.6 kg/Mg (9.2 lb/ton) and averaged 3.2 (6.4 lb/ton). The emission factors developed from the C-rated data ranged from 1.4 kg/Mg (2.9 lb/ton) to 3.4 kg/Mg (6.7 lb/ton) and averaged 2.9 kg/Mg (5.7 lb/ton). The B- and C-rated data were combined for an average emission factor for uncontrolled NO_x emissions from dry process kilns of 3.0 kg/Mg (6.0 lb/ton). This average emission factor is assigned a rating of D.

Carbon monoxide. For CO emissions from a long dry process kilns, the results from three emission tests were available. The data from one of the tests was unrated and were discarded. The remaining data consist of the results of a C-rated test on an ESP-controlled kiln (0.11 kg/Mg [0.22 lb/ton]) and a D-rated test on a fabric filter-controlled kiln (0.10 kg/Mg [0.20 lb/ton]). Because ESP's and fabric filters are expected to have negligible effects on CO emissions, the data were treated as measurements of uncontrolled CO emissions. The emission factors from both tests were combined to yield an E-rated emission factor of 0.11 kg/Mg (0.21 lb/ton) for CO emissions from long dry process kilns.

Carbon dioxide. For CO_2 emissions from long dry process kilns, a total of seven data sets were available on measurements of CO_2 emissions from kilns controlled with various control devices, none of which are expected to have significant effects on CO_2 emissions. Therefore, all data sets were treated as measurements of uncontrolled CO_2 emissions. One of the tests was rated D and was discarded. Three of the data sets were rated B, and the other three data sets were rated C. The emission factors developed from the B-rated data ranged from 900 kg/Mg (1,800 lb/ton) to 1,100 kg/Mg (2,100 lb/ton) and averaged 1,000 (2,000 lb/ton). The emission factors developed from the C-rated data ranged from

420 kg/Mg (830 lb/ton) to 1,000 kg/Mg (2,000 lb/ton) and averaged 780 kg/Mg (1,500 lb/ton). The B- and C-rated data were combined for an average emission factor for uncontrolled CO_2 emissions from long dry process kilns of 900 kg/Mg (1,800 lb/ton). In comparison to the theoretical average emission factor for CO_2 emissions (1,100 kg/Mg [2,100 lb/ton]) from coal-fired dry process kilns discussed in Section 4.2.2, the magnitude of this average emission factor appears to be reasonable. This average emission factor is assigned a rating of D.

Volatile Organic Compounds. For long dry process kilns, data were available from two tests of TOC emissions and one test of TNMOC emissions. The tests were conducted on kilns with dry PM controls (ESP's or fabric filters), which should have negligible effects on VOC emissions, and all three tests were rated C. The TOC data were 0.024 kg/Mg (0.048 lb/ton) and 0.0044 kg/Mg (0.0088 lb/ton) and averaged 0.014 kg/Mg (0.028 lb/ton). The results of the TNMOC test were 0.23 kg/Mg (0.45 lb/ton), which are considerably higher than the emission factors developed from the TOC tests. Because TOC emissions should be higher, the emission factor developed from the TNMOC data was not incorporated into the revised AP-42 section. The TOC emission factor is rated E.

4.2.5.3 Dry Preheater Kilns. Of the 32 data sets from which criteria pollutant emission factors were developed for dry preheater kiln emissions, 1 was rated A, 19 were rated B, 11 were rated C, and 1 was rated D. All of the tests documented were conducted on coal-fired dry preheater process kilns. The average emission factors developed from these data sets are provided in Table 4-13. The following paragraphs describe how these average emission factors for dry preheater process kilns were developed.

Filterable PM. For filterable PM emissions from uncontrolled dry preheater kilns, one A-rated data set was available. The results from this test were used to develop a D-rated emission factor.

For filterable PM emissions controlled with an ESP, a single B-rated data set was available. The results from this test also were used to develop a D-rated emission factor.

For filterable PM emissions from a dry preheater kiln controlled with a fabric filter, data from three B-rated tests and five C-rated tests were available. The emission factors developed from the B-rated data ranged from 0.10 kg/Mg (0.19 lb/ton) to 0.14 kg/Mg (0.28 lb/ton) and averaged 0.12 kg/Mg (0.23 lb/ton). The emission factors developed from the C-rated data ranged from 0.031 kg/Mg (0.063 lb/ton) to 0.45 kg/Mg (0.89 lb/ton) and averaged 0.13 kg/Mg (0.26 lb/ton). The emission factors develop from all eight tests were combined to yield an average emission factor of 0.13 kg/Mg (0.25 lb/ton) for filterable PM emissions from dry preheater kilns controlled with fabric filters. Because of the relatively large number of tests upon which it is based, this emission factor is rated C.

Condensible inorganic PM. For condensible inorganic PM emissions from dry preheater kilns controlled with fabric filters, data from a single B-rated test were available. These data were used to develop a D-rated emission factor of 0.017 kg/Mg (0.033 lb/ton).

Sulfur dioxide. For SO_2 emissions from dry preheater kilns, four data sets were available. All four data sets consist of measurements of SO_2 emissions from fabric filter-controlled dry preheater process kilns. These data were treated as measurements of uncontrolled SO_2 emissions. Two of the data sets were rated B and two of the data sets were rated C. The emission factors developed from the B-rated data were 0.055 kg/Mg (0.11 lb/ton) and 1.0 kg/Mg (2.0 lb/ton) and averaged 0.53 kg/Mg (1.1 lb/ton). The emission factors developed from the C-rated data were 0.0026 kg/Mg (0.0052 lb/ton)

and 0.042 kg/Mg (0.083 lb/ton) and averaged 0.022 kg/Mg (0.044 lb/ton). The emission factors develop from all four tests were combined to yield an average emission factor of 0.27 kg/Mg (0.55 lb/ton) for SO_2 emissions from dry preheater process kilns controlled with fabric filters. This average emission factor is assigned a rating of D.

Nitrogen oxides. For NO_x emissions from dry preheater kilns, three data sets were available. All three of the tests were conducted on kilns controlled with fabric filters. Because fabric filters are expected to have negligible effects on NO_x emissions, all data sets were treated as measurements of uncontrolled NO_x emissions. Two of these data sets were rated B, and the remaining data set was rated C. The emission factors developed from the B-rated data were 2.9 kg/Mg (5.8 lb/ton) and 3.1 kg/Mg (6.2 lb/ton) and averaged 3.0 kg/Mg (6.0 lb/ton). The emission factor developed from the C-rated data was 1.2 kg/Mg (2.4 lb/ton). The B- and C-rated data were combined for an average emission factor for uncontrolled NO_x emissions from dry preheater kilns of 2.4 kg/Mg (4.8 lb/ton). This average emission factor is assigned a rating of D.

Carbon monoxide. For CO emissions from dry preheater kilns, data from a single B-rated test were available. These data were used to develop a D-rated emission factor of 0.49 kg/Mg (0.98 lb/ton).

Carbon dioxide. For CO_2 emissions from dry preheater process kilns, 11 data sets were available on measurements of CO_2 emissions from kilns controlled with various control devices, none of which are expected to have significant effects on CO_2 emissions. Therefore, all data sets were treated as measurements of uncontrolled CO_2 emissions. Eight of the data sets were rated B, and the other three data sets were rated C. The emission factors developed from the B-rated data ranged from 770 kg/Mg (1,500 lb/ton) to 1,000 kg/Mg (2,000 lb/ton) and averaged 890 (1,800 lb/ton). The emission factors developed from the C-rated data ranged from 790 kg/Mg (1,600 lb/ton) to 1,100 kg/Mg (2,100 lb/ton) and averaged 950 kg/Mg (1,900 lb/ton). The B- and C-rated data were combined for an average emission factor for uncontrolled CO_2 emissions from dry preheater process kilns of 900 kg/Mg (1,800 lb/ton). In comparison to the theoretical average emission factor for CO_2 emissions (930 kg/Mg [1,900 lb/ton]) from coal-fired preheater kilns discussed in Section 4.2.2, the magnitude of this average emission factor appears to be reasonable. Because of the relatively large number of tests upon which it is based, this emission factor is rated C.

Volatile Organic Compounds. For preheater kilns, data were available from one test of TOC emissions and one test of VOC emissions. Both tests were conducted on the same fabric filter controlled kiln. Because fabric filters should have negligible effects on VOC emissions, the results were considered to be measurements of uncontrolled emissions. The TOC emission factor, which is based on B-rated data, is rated D. Because the VOC emission factor was developed from D-rated data, it was not incorporated into the revised AP-42 section.

4.2.5.4 Preheater/Precalciner Kilns. Of the 102 data sets from which emission factors were developed for preheater/precalciner kiln emissions, 4 were rated A, 42 were rated B, 43 were rated C, 10 were rated D, and 3 were not rated. All of the tests documented were conducted on coal-fired preheater/precalciner kilns. The average emission factors developed from these data sets are included in Table 4-14. The following paragraphs describe how these average emission factors for preheater/precalciner kilns were developed.

Filterable PM. For filterable PM emissions controlled with an ESP, data from a single B-rated test were available. These data were used to develop a D-rated emission factor of 0.24 kg/Mg (0.48 lb/ton).

For fabric filter-controlled filterable emissions from a preheater/precalciner kiln, data were available from 17 tests. After combining the results of multiple tests on the same kiln, the number of data sets was reduced to seven. One of these data sets was rated A, three of the data sets were rated B, two of the data sets was rated C, and the remaining data set was rated D. The C- and D-rated data were discarded. The A-rated data were used to develop an emission factor of 0.12 kg/Mg (0.24 lb/ton). The emission factors developed from the B-rated data ranged from 0.0062 kg/Mg (0.012 lb/ton) to 0.26 kg/Mg (0.52 lb/ton) and averaged 0.099 kg/Mg (0.19 lb/ton). The A- and B-rated data were combined for an average emission factor for fabric filter-controlled filterable PM emissions from dry preheater/precalciner process kilns of 0.10 kg/Mg (0.21 lb/ton). This average emission factor is assigned a rating of D.

Condensible inorganic PM. For condensible inorganic PM emissions from preheater/precalciner kilns, data from six emission tests were available: a B-rated test on an ESP-controlled kiln, four B-rated tests on fabric filter-controlled kilns, and one D-rated test on a fabric filter-controlled kilns. For fabric filter-controlled condensible inorganic PM emissions, the D-rated data set was discarded. Two of the B-rated tests were conducted on the same kiln and resulted in an emission factor of 0.0050 kg/Mg (0.010 lb/ton). The data from the remaining B-rated tests resulted in an emission factors of 0.023 kg/Mg (0.047 lb/ton) and 0.14 kg/Mg (0.28 lb/ton). When combined, these emission factors yield an average emission factor of 0.056 kg/Mg (0.11 lb/ton) for condensible inorganic PM emissions from dry preheater/precalciner process kilns controlled with fabric filters. This emission factor is significantly lower than the emission factor developed from the ESP-controlled kiln test (0.14 kg/Mg [0.29 lb/ton]). Because it is unlikely that the difference in condensible PM emissions control achieved by ESP's and fabric filters is so pronounced, and due to the overall sparsity of test data, the results of all tests were combined. The data yield an average controlled emission factor for condensible inorganic PM emissions of 0.078 kg/Mg (0.16 lb/ton). This emission factor is rated D.

Sulfur dioxide. For SO_2 emissions from dry preheater/precalciner process kilns, a total of 21 data sets were available. Two of the data sets consist of measurements of SO_2 emissions from an ESP-controlled kiln, one of the tests was conducted on a kiln controlled with a spray tower, one of the tests was conducted on a kiln controlled with both a spray tower and ESP, and the remaining 17 tests were on fabric filter-controlled kilns.

Because ESP's and fabric filters are expected to have negligible effects on SO_2 emissions, the results of these tests were treated as measurements of uncontrolled SO_2 emissions. The results of one of the tests were rated D and were discarded. Combining the results of multiple tests on the same kiln, reduced the number of data sets to five B-rated data sets and two C-rated data sets. The emission factors developed from the B-rated data ranged from 0.016 kg/Mg (0.033 lb/ton) to 1.4 kg/Mg (2.9 lb/ton) and averaged 0.54 kg/Mg (1.1 lb/ton). The emission factors developed from the C-rated data were 0.75 kg/Mg (1.5 lb/ton) and 0.43 kg/Mg (0.85 lb/ton). The C-rated data were discarded because of the relatively large number of B-rated data sets available. The average emission factor developed from the B-rated data is assigned a rating of D.

The test data on the spray tower-controlled kilns both were rated C. The emission factors developed from the results of these two tests were 0.40 kg/Mg (0.79 lb/ton) and 0.60 kg/Mg (1.2 lb/ton) and averaged 0.50 kg/Mg (1.0 lb/ton). This average emission factor is rated E.

Nitrogen oxides. For NO_x emissions from dry preheater/precalciner process kilns, a total of 20 data sets were available. Two of the tests was conducted on a kiln controlled with an ESP, one test was conducted on a kiln with an unspecified control device, and the remaining 16 tests were conducted on fabric filter-controlled kilns. Because ESP's and fabric filters are expected to have negligible effects on NO_x emissions, all data sets were treated as measurements of uncontrolled NO_x emissions; the unspecified control device test was rated D and discarded. After combining the results of multiple tests on the same kiln, the number of data sets was reduced to five B-rated data sets and two C-rated data sets. The emission factors developed from the B-rated data ranged from 1.1 kg/Mg (2.2 lb/ton) to 3.6 kg/Mg (7.1 lb/ton) and averaged 2.1 kg/Mg (4.2 lb/ton). The emission factors developed from the C-rated data ranged from 1.5 kg/Mg (3.1 lb/ton) to 4.8 kg/Mg (9.5 lb/ton) and averaged 3.4 kg/Mg (6.7 lb/ton). Only the B-rated data were used. The average emission factor developed from the B-rated data is assigned a rating of D.

Carbon monoxide. For CO emissions from preheater/precalciner kilns, data were available from 12 tests on 6 kilns. One of the tests was conducted on a kiln controlled with an ESP and the remaining 11 tests were conducted on fabric filter-controlled kilns. Because ESP's and fabric filters are expected to have negligible effects on CO emissions, all data sets were treated as measurements of uncontrolled CO emissions. After combining the results of multiple tests on the same kiln, the number of data sets was reduced to one A-rated test, three B-rated data sets, and one C-rated data set. The results of the A-rated test yielded an emission factor of 4.4 kg/Mg (8.7 lb/ton). The emission factors developed from the B-rated data ranged from 0.60 kg/Mg (1.2 lb/ton) to 1.3 kg/Mg (2.5 lb/ton) and averaged 0.86 kg/Mg (1.7 lb/ton). The C-rated data yielded an average emission factor of 0.50 kg/Mg (0.99 lb/ton). The C-rated data were discarded and an average emission factor of 1.8 kg/Mg (3.7 lb/ton) was developed from the combined A- and B-rated data. This emission factor is rated D.

Carbon dioxide. For CO_2 emissions from preheater/precalciner kilns, 12 data sets were available for ESP- or fabric filter-controlled kilns. All data sets were treated as measurements of uncontrolled CO_2 emissions. After combining the results of multiple tests on the same kiln, the number of data sets was reduced to six. One of these data sets was rated A, three of the data sets were rated B, one data set was rated C, and one of the data sets was rated D. The A-rated data resulted in an emission factor of 970 kg/Mg (1,900 lb/ton). The emission factors developed from the B-rated data ranged from 820 kg/Mg (1,600 lb/ton) to 1,000 kg/Mg (2,100 lb/ton) and averaged 900 (1,800 lb/ton). An emission factor of 1,400 kg/Mg (2,800 lb/ton) was developed from the C-rated data. The A- and B-rated data were combined for an average emission factor for uncontrolled CO_2 emissions from preheater/precalciner kilns of 920 kg/Mg (1,800 lb/ton). This average emission factor is higher than the average CO^2 emission factor for preheater kilns. However, because preheater/precalciner kilns are more efficient than preheater kilns, the average CO_2 emission factor for preheater/precalciner kilns should be lower than the CO_2 emission factor for preheater kilns. Therefore, it is recommended that the average CO_2 emission factor for preheater kilns be used as an upper estimate for the emission factor for preheater/precalciner kilns. Because this emission factor is not based on preheater/precalciner kiln test data, it is assigned a rating of E.

Volatile Organic Compounds. For preheater/precalciner kilns, data were available from ten tests of TOC emissions conducted on three kilns all of which were controlled with fabric filters. After combining the results of multiple tests on the same kiln, the number of data sets was reduced to three, one A-rated, one B-rated, and one C-rated tests. Because fabric filters should have negligible effects on VOC emissions, the results were considered to be measurements of uncontrolled emissions. The C-rated data were discarded, and the results of the A- and B-rated tests were combined to yield an average emission factor of 0.059 kg/Mg (0.12 lb/ton) for uncontrolled TOC emissions from preheater/precalciner kilns. This emission factor is rated D.

4.2.5.5 Noncriteria Pollutant Emissions From Portland Cement Kilns. The remaining data sets on emissions from portland cement kilns consist of measurements of a number of inorganic and organic compounds. For the majority of these compounds, data are available from only one or two emission tests. In addition, the data do not appear to indicate significant differences in emissions of the same compounds from different types of pyroprocesses. Therefore, the data from all four types of kilns (wet process, dry process, dry preheater process, and preheater/precalciner process) were combined to yield generic emission factors for portland cement kilns. These emission factors are summarized in Table 4-15.

Due to the large number of compounds and the relatively small number of data sets on each type of compound, a discussion of how data for each of these compounds were combined to yield average emission factors is not presented. In general, data were combined using the methodology described above for criteria pollutant emission factors. When available, only A- and B-rated data were used to develop average emission factors. C-rated data were combined with B-rated data if the number of C-rated data sets was significant in comparison to the number of B-rated data sets. D-rated data were used, alone or in combination with C-rated data, only if no A- or B-rated data were available, and all unrated data sets were discarded. Emission factors are reported only if the majority of runs for a test were above detection limits. In those cases, only runs above the detection limits were considered in the average.

4.2.5.6 Clinker Coolers. Of the 35 data sets from which emission factors were developed for clinker cooler emissions, 2 were rated A, 13 were rated B, 1 was rated C, and 19 were not rated. The unrated data consist of the results of metal analyses for a single Method 5 run filter catch. All unrated data were eliminated from consideration for inclusion in AP-42. The remaining data sets consist of the results of measurements of filterable PM (10 tests) and condensible inorganic PM (6 tests) emissions. The average emission factors developed from the data are summarized in Table 4-16. The following paragraphs highlight how these emission factors were developed.

Filterable PM. For clinker cooler controlled with ESP's, a single B-rated test report was available. The data resulted in an emission factor of 0.048 kg/Mg (0.096 lb/ton). This emission factor is rated D.

For clinker coolers controlled with fabric filters, the results of five tests were available. The results of all five tests were rated B, and two of the tests were conducted on the same clinker cooler. The emission factor developed from the data ranged from 0.0060 kg/Mg (0.012 lb/ton) to 0.24 kg/Mg (0.47 lb/ton) and averaged 0.068 kg/Mg (0.13 lb/ton). This emission factor is rated D.

For clinker coolers controlled with gravel bed filters, data from four emission tests were available. The results of one of the tests was rated A (0.080 kg/Mg [0.16 lb/ton]), the results of two of the tests were rated B (0.055 kg/Mg [0.11 lb/ton] and 0.18 kg/Mg [0.35 lb/ton]), and the results of the remaining

test was rated C (0.070 kg/Mg [0.14 lb/ton]). The C-rated data were discarded and an average emission factor of 0.11 kg/Mg (0.21 lb/ton) was developed from the A- and B-rated data. This emission factor is rated D.

Emission factors for PM-10 emissions from gravel bed filter-controlled clinker coolers also were developed using the particle size data presented in Reference 79 and the average emission factors described in the preceding paragraphs.

Condensible inorganic PM. The condensible inorganic PM data consist of the results of one A-rated test and five B-rated tests. One of the B-rated tests was conducted on a clinker cooler controlled with an ESP. The results of this test were used to develop a D-rated emission factor of 0.0038 kg/Mg (0.0075 lb/ton). Three of the B-rated tests were conducted on clinker coolers controlled with fabric filters. The results of these tests yielded a D-rated average emission factor of 0.0084 kg/Mg (0.017 lb/ton). The A-rated and remaining B-rated tests were conducted on clinker coolers controlled with gravel bed filters. The data from these tests resulted in a D-rated average emission factor of 0.0045 kg/Mg (0.0090 lb/ton).

4.2.5.7 Other Processes. A total of 53 data sets were available for measurements of emissions from portland cement manufacturing processes other than kilns and coolers. These other processes included raw and finished material crushing, grinding, screening, and transfer. Eleven of the data sets were rated B and eight data sets were C-rated. All of these data sets consist of measurements of filterable PM emissions. Table 4-17 summarizes the average emission factors developed from these data.

The results of a single B- or C-rated test were available for the following sources: raw mill feed belt, raw mill weigh hopper, raw mill air separator, finishing mill feed belt, finishing mill weigh hopper, primary limestone crushing, primary limestone screening, limestone transfer, and secondary limestone screening and crushing. The emission factors developed from these tests are presented directly in Table 4-17. The results of two to five B- or C-rated tests were available for raw mills, finishing mills, and finishing mill air separators. Average emission factors for these sources were developed by averaging the results of all of the emission tests. The average emission factors based on C-rated data were rated E. The average emission factors based on multiple B-rated data sets were rated D. However, the average emission factors based on a single B-rated data set were rated E. Because of difficulty in measuring emissions from such sources, the results are likely to be less representative of average emissions.

The remaining 34 data sets consist of unrated results of measurements of trace metal emissions from various sources. Because these data were unrated, emission factors developed from the data were not included in the revised AP-42 section.

4.2.6 Analysis of the Uncertainty in Kiln Emission Factors for Portland Cement Kilns

Because a substantial quantity of data is available on NO_x, SO_2, and PM emissions from portland cement plants, these data were analyzed statistically to develop a better understanding of the uncertainty in the emission factors. The objectives of this uncertainty analysis were to evaluate the precision in calculated average emission factors and to characterize the plant-to-plant variability in plant-specific emission factors. The analyses were conducted in three stages. First, the data were examined graphically in a series of box plots to gain insight about the variability of emissions as a function of kiln

type, air pollution control device (APCD), and data quality rating. Next, "average" emission factors were obtained for different groupings of cement kiln types for two sets of data (A-, B-, and C-rated data and A- and B-rated data only) using a least squares analysis procedure. This procedure is very similar to the averaging procedure typically used to generate AP-42 emission factors, but it has certain advantages for the uncertainty analysis because it provides estimates of the precision of the calculated emission factors. The final stage of the analysis used variance components analysis procedures to develop final estimates of the precision of the calculated emission factors and to estimate the plant-to-plant variability in emission factors. The paragraphs below discuss these analyses further and present the results of the analyses.

Figures 4-1 through 4-4 present box plots of the run-specific emission factors for NO_x, SO_2, uncontrolled PM, and controlled PM, respectively. The emission factors in the figures are presented in units of lb/ton. For each particular configuration of kiln type, APCD, and data rating, the box plot identifies the interquartile range of the data (i.e., the 25th to 75th percentiles) with a box, with a horizontal bar in each box identifying the median of the data. The mean of the data is identified with an asterisk, and outliers are identified as moderate and extreme with a diamond and a box, respectively. The width of each box is proportional to the logarithm of the number of data points used to construct the box. For the NO_x emission data in Figure 1, plots are developed for each type of kiln and data rating. For the SO_2 emission data in Figure 2 and the controlled PM emission data in Figure 4, separate plots are developed for each combination of kiln type, APCD, and data rating. In the kiln group identifiers in Figures 2 and 4, the first letter represents kiln type (W=wet, D=dry, H=preheater, and C=preheater/precalciner); the second letter represents APCD (U=uncontrolled, E=Esp, and F=fabric filter); and the third letter represents the data rating for the group of tests. Note that for all plots, only A-, B-, and C-rated data were plotted. Figure 3 shows plots of the uncontrolled kiln PM emission data as a function of kiln type and data rating.

Based on a visual examination, there appears to be no consistent pattern of differences between emission factors as a function of data rating, but patterns do exist for some pollutants. The NO_x data in Figure 1 and the controlled PM data in Figure 4 show little variation between the B- and C-rated data, and, for the case in which the box locations do differ, there is no consistent pattern of one of the ratings yielding the greater emission factor. However, the SO_2 data in Figure 2 do exhibit a general pattern of the C-rated data having substantially lower levels than do the B-rated data. Because the some of the differences are quite large, further examination of the SO_2 data is warranted. Other important observations from the box plots are that the NO_x emission factors show little variability across kiln types; the emission factors for SO_2 are substantially lower for preheater and preheater/precalciner kilns than for wet and dry kilns; there is a slight pattern of lower SO_2 emission factors with fabric filters than with ESP's or no controls but the difference may not be significant; and there is a substantial difference between controlled and uncontrolled PM emissions but there are no apparent differences in the controlled emissions as a function of either kiln type or control device.

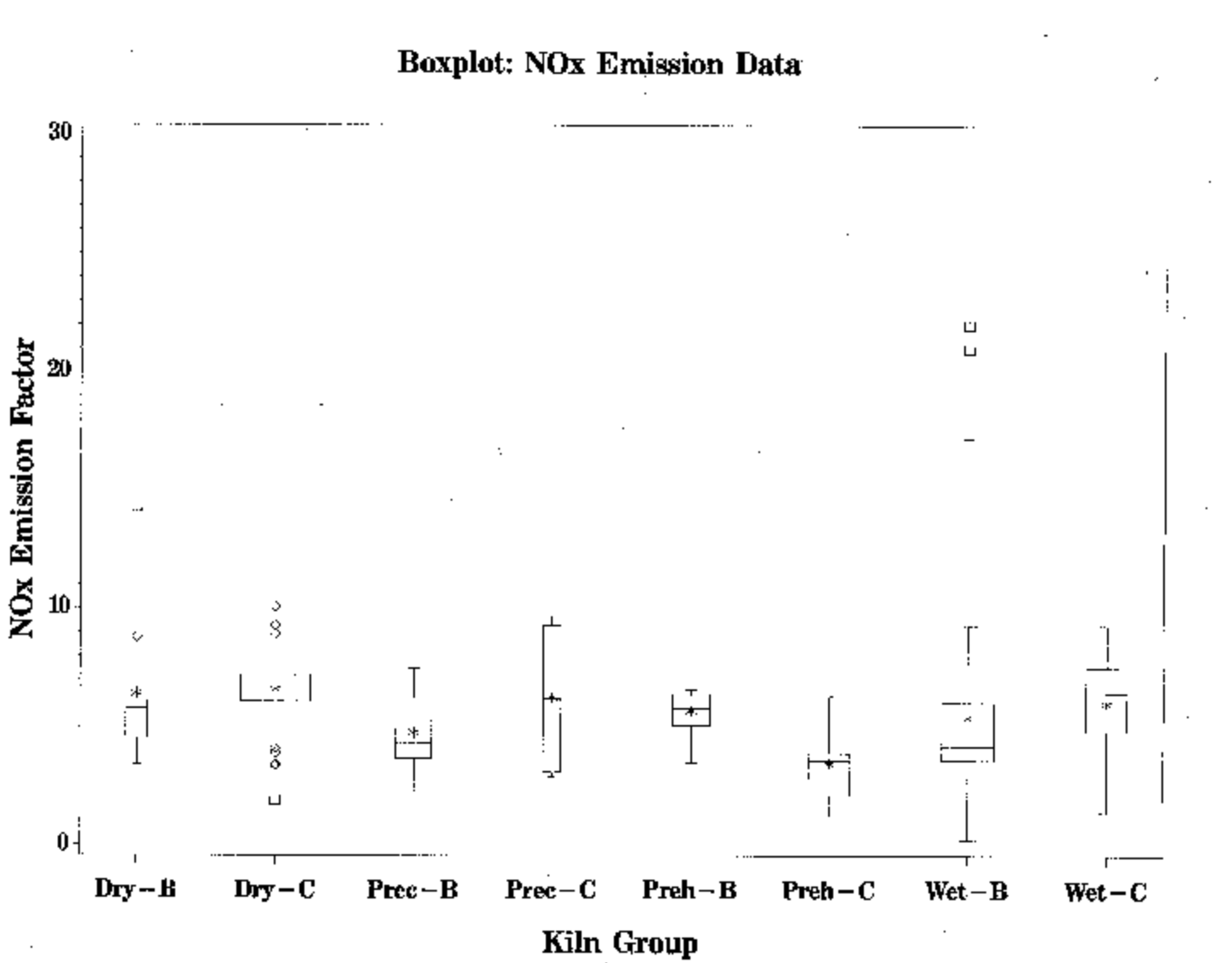

Figure 4-1. Boxplot of NO_x emission factors for portland cement kilns.

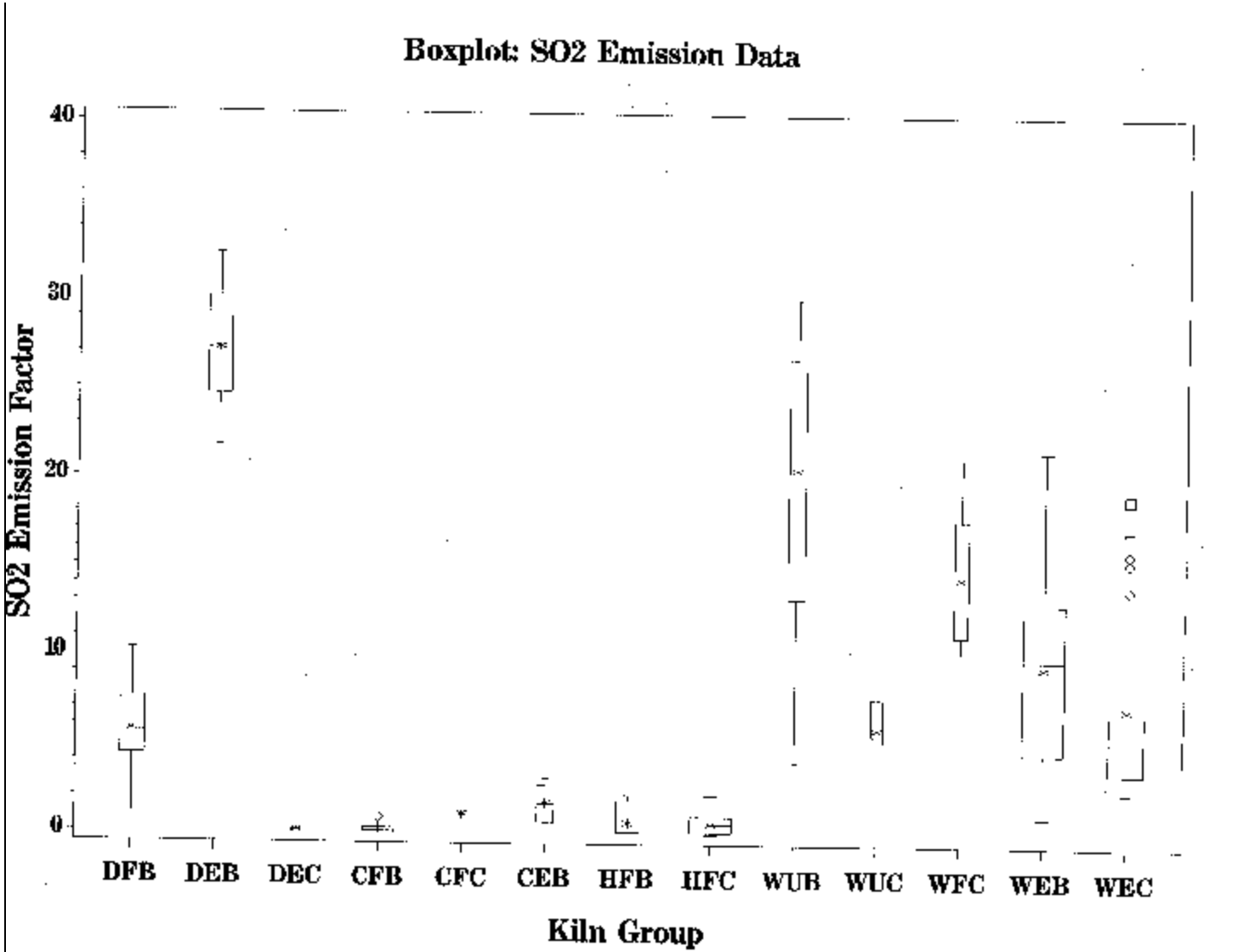

Figure 4-2. Boxplot of SO_2 emission factors for portland cement kilns.

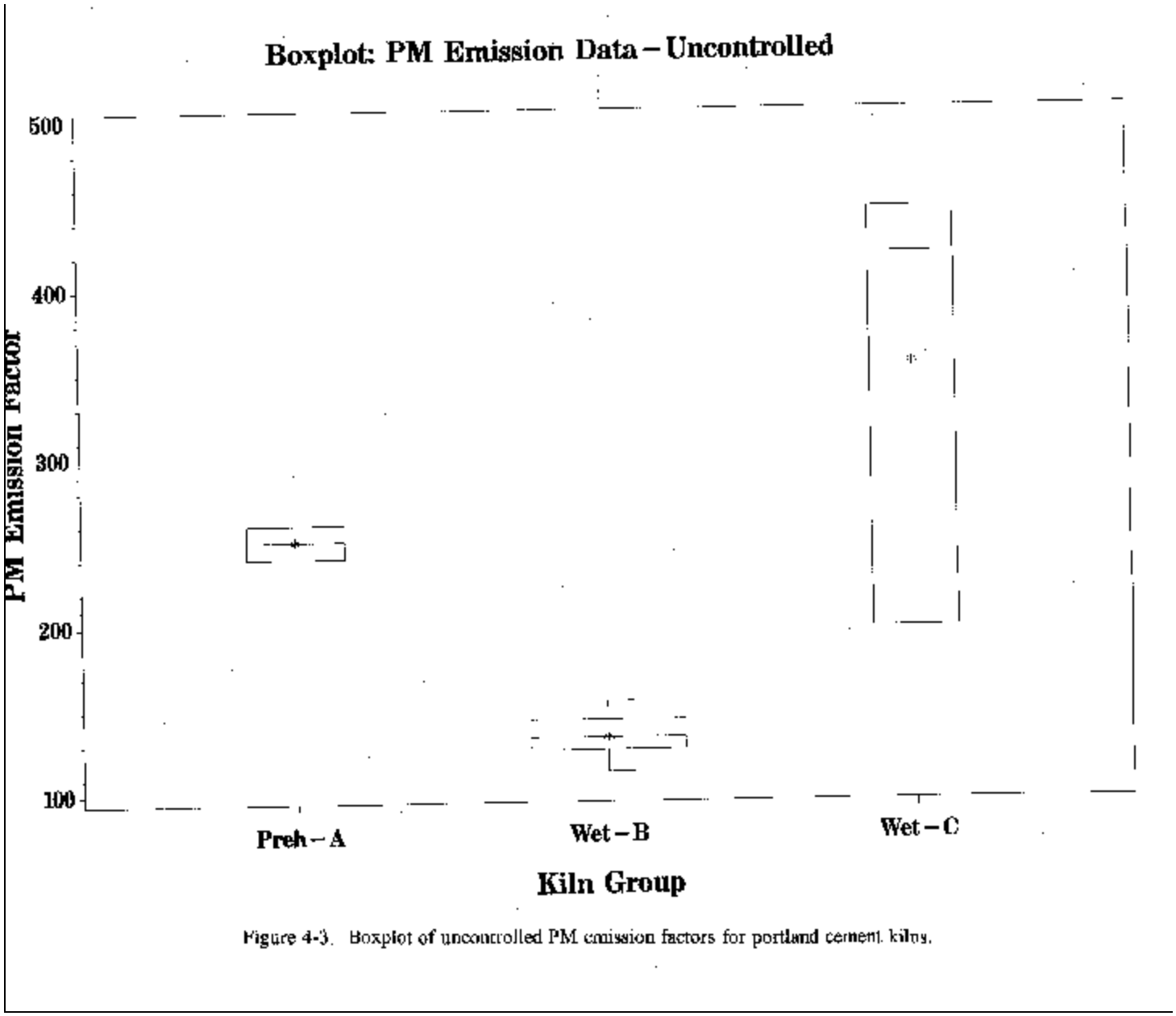

Figure 4-3. Boxplot of uncontrolled PM emission factors for portland cement kilns.

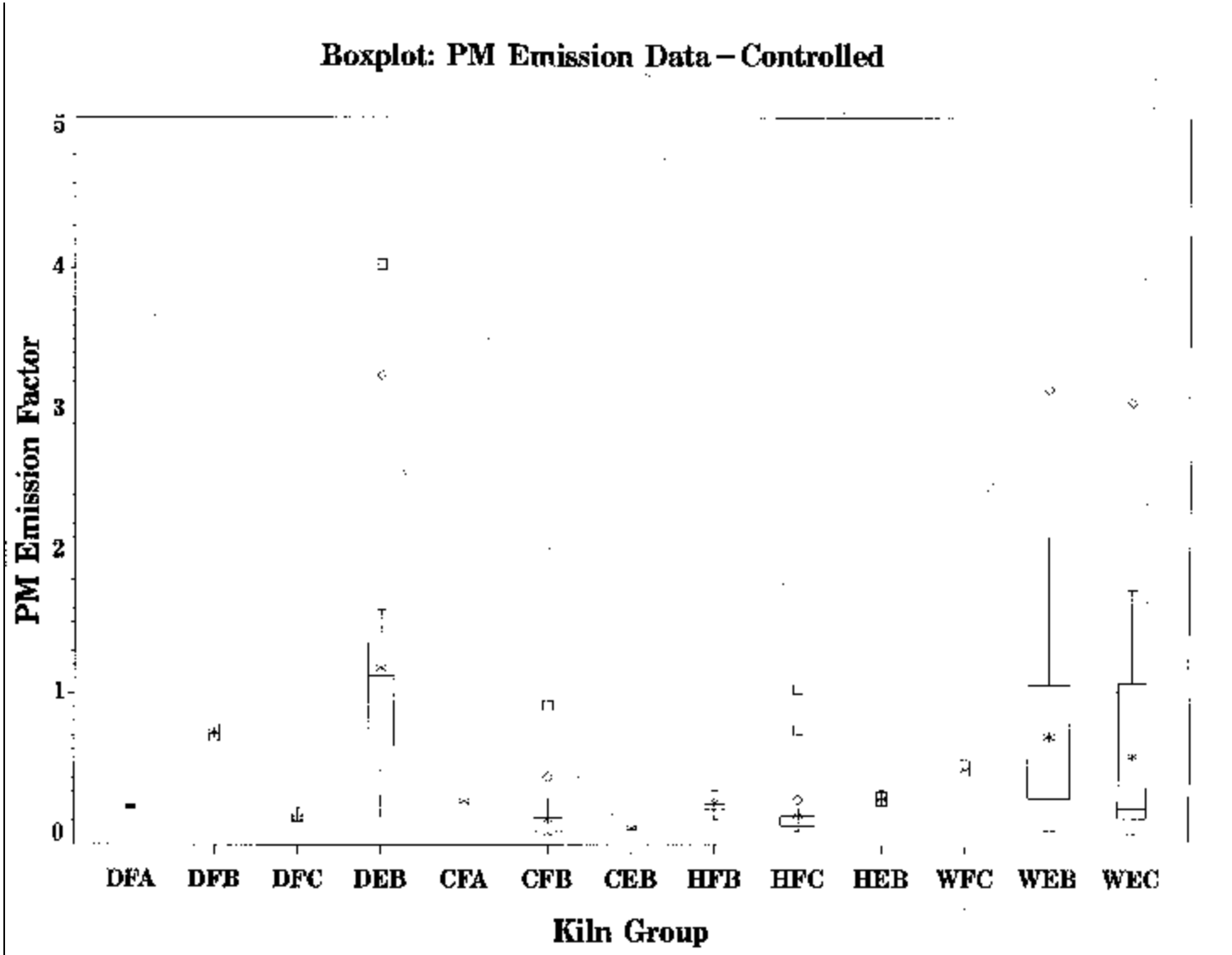

Figure 4-4. Boxplot of controlled PM emission factors for portland cement kilns.

Based on the observations from the graphical analyses, the decision was made to develop emission factor estimates for a variety of kiln type/APCD/data rating groupings. The estimates were calculated using a general linear model (GLM) procedure that obtained the final estimates by weighing each facility tested within the group of interest equally and by weighing all runs within each facility equally. For all groupings of interest, estimates were calculated based on all A-, B-, and C-rated data and on A- and B-rated data only. Because the primary interest in this analysis was on the uncertainty in the emission factors, only those groups with more than two facilities were evaluated. The results of the analysis are shown in Table 4-18. The calculated AP-42 emission factors are also presented for comparison. For the GLM results, both the estimate and the standard errors of the estimates are presented. In general, the estimates generated with the A-, B-, and C-rated data agree closely with those generated by the A- and B-rated data only, and the results do not appear to differ statistically, although formal statistical tests were not conducted. The two groups for which there are major differences are uncontrolled PM and SO_2 emission factors for wet process kilns. Because these differences are so large, there appears to be an advantage to using only the A- and B-rated data for these groups. For the other groups, the use of A-, B-, and C-rated data appears to be warranted because it results in little change in the point estimate and provides a more precise estimate as evidenced by the lower standard error. These results indicate that with a few exceptions, the standard errors of the emission factors are reasonably small (10 percent of the estimate), which indicates that the 95 percent confidence interval for most population mean emission factors is in the range of ±20 percent of the estimate.

The final stage of the analysis focused on characterizing emission factor variability. Because the earlier analyses suggest that variability was consistent across some kiln type/APCD groupings, further grouping was done for these analyses in order to provide more stable variance estimates. Estimates of the between-plant and within-plant variance were obtained using a restricted maximum likelihood variance components procedure. The results of these analyses are presented in Table 4-19, which shows estimates of both between-plant and within-plant variances (the variance is the square of the standard deviation) for each grouping of interest.

There are three results of note in Table 4-19. First, for all possible groupings, the plant-to-plant variability is substantially larger than the within-plant variability. Furthermore, for all of the groupings except FF/ESP-controlled PM emissions, the between-plant standard deviation is on the same order of magnitude as the mean emission factor estimate. This result indicates that the emission factor for any particular plant within the categories modelled can vary substantially from the mean emission factor for that category. Second, the NO_x results indicate that the plant-to-plant variability with all kiln types averaged together (variance of 18) is smaller than the between-plant variance averaged across kiln types when separate emission factors are developed for each kiln type. These results suggest that consideration be given to developing a single average emission factor for NO_x. Finally, the plant-to-plant variance for uncontrolled PM and SO_2 emissions is so large that AP-42 readers should show care in applying the average emission factor to specific facilities. On the other hand, because a small number of plants are involved in both variance calculations, the variance results should be interpreted cautiously.

TABLE 4-18. SUMMARY OF EMISSION FACTOR ESTIMATES

Pollutant	Kiln type	APCD	Revised AP-42 emission factor, lb/ton	A-, B-, C- data		A-, B- data	
				Emission factor, lb/ton	Standard error	Emission factor, lb/ton	Standard error
NO_x	Wet	--	7.4	6.5	0.21	7.2	0.25
	Dry	--	6.0	6.0	0.32	6.7	0.61
	Preheater	--	4.8	4.8	0.34	6.0	0.50
	Precalciner	--	4.2	4.8	0.23	4.2	0.33
	Combined	--		5.7	0.13	6.1	0.18
SO_2	Wet	Uncontrolled		13	1.3	21	1.7
		ESP		7.4	0.53	7.5	0.82
		Combined	8.2	8.4	0.52	8.2	0.84
	Dry	ESP		14	1.4	27	1.2
		FF		4.5	1.4	4.5	1.5
		Combined	10	8.4	1.0	10.1	1.0
	Preheater	FF	0.55	0.56	0.89	1.1	1.4
	Precalciner						
		FF		0.78	0.70	0.31	0.98
		Combined	1.1	1.1	0.83	1.0	1.0
PM	Wet	Uncontrolled	130	210	18	130	4.4
		ESP	0.77	0.68	0.056	0.61	0.071
		FF	0.46	[a]		[a]	
	Dry	ESP	1.0	1.2	0.083	1.2	0.095
		FF	0.2	0.16	0.17	0.20	0.27
	Preheater	Uncontrolled	250	[a]		[a]	
		ESP	0.26	[a]		[a]	
		FF	0.25	0.25	0.082	0.23	0.14
	Precalciner	ESP	0.048	[a]		[a]	
		FF	0.21	0.16	0.071	0.17	0.10
	All	UNC		220	14	170	3.6
		ESP		0.73	0.044	0.72	0.054
		FF		0.22	0.053	0.20	0.077

[a]Not calculated due to small data set.

TABLE 4-19. SUMMARY OF EMISSION FACTOR VARIABILITY

Pollutant	Kiln	Control	Variance	
			Between Plant	Within Plant
NO_x	All	--	18[a]	0.031
			13[b]	0.031
SO_2	All[c]	Uncontrolled[d]	23,000	1,500
		FF[d]	2.8	0.062
		ESP[d]	411	13
	All	Combined[e]		
PM	All	Uncombined	8.5×10^7	1.4×10^6
		FF/ESP	0.0043	0.00028

[a]Based on model for kiln-specific emission factors.
[b]Based on emission factor averaged across kiln types.
[c]Separate estimates obtained by kiln type so variance estimates are related to variability within a kiln type.
[d]Based on using data for only specific controls.
[e]Based on use of all data in a single model with emission factors specific to control method.

REFERENCES FOR SECTION 4

1. *Emissions From Wet Process Cement Kiln and Clinker Cooler at Maule Industries, Inc.*, ETB Test No. 71-MM-01, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.

2. *Emissions From Wet Process Cement Kiln and Clinker Cooler at Ideal Cement Company*, ETB Test No. 71-MM-03, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.

3. *Emissions From Wet Process Cement Kiln and Finish Mill Systems at Ideal Cement Company*, ETB Test No. 71-MM-04, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.

4. *Emissions From Dry Process Cement Kiln at Dragon Cement Company*, ETB Test No. 71-MM-05, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.

5. *Emissions From Wet Process Clinker Cooler and Finish Mill Systems at Ideal Cement Company*, ETB Test No. 71-MM-06, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.

6. *Emissions From Wet Process Cement Kiln at Giant Portland Cement*, ETB Test No. 71-MM-07, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.

7. *Emissions From Wet Process Cement Kiln at Oregon Portland Cement*, ETB Test No. 71-MM-15, U.S. Environmental Protection Agency, Research Triangle Park, NC, March 1972.

8. *Emissions From Dry Process Raw Mill and Finish Mill Systems at Ideal Cement Company*, ETB Test No. 71-MM-02, U.S. Environmental Protection Agency, Research Triangle Park, NC, April 1972.

9. *Part I, Air Pollution Emission Test: Arizona Portland Cement*, EPA Project Report No. 74-STN-1, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 1974.

10. *Characterization of Inhalable Particulate Matter Emissions From a Dry Process Cement Plant*, EPA Contract No. 68-02-3158, Midwest Research Institute, Kansas City, MO, February 1983.

11. *Characterization of Inhalable Particulate Matter Emissions From a Wet Process Cement Plant*, EPA Contract No. 68-02-3158, Midwest Research Institute, Kansas City, MO, August 1983.

12. *Particulate Emission Testing at Lone Star Industries' Nazareth Plant*, Lone Star Industries, Inc., Houston, TX, January 1978.

13. *Particulate Emissions Testing at Lone Star Industries' Greencastle Plant*, Lone Star Industries, Inc., Houston, TX, July 1977.

14. *Gas Process Survey at Lone Star Cement, Inc.'s Roanoke No. 5 Kiln System*, Lone Star Cement, Inc., Cloverdale, VA, October 1979.

15. *Test Report: Stack Analysis for Particulate Emissions: Clinker Coolers/Gravel Bed Filter*, Mease Engineering Associates, Port Matilda, PA, January 1993.

16. *Source Emissions Survey of Oklahoma Cement Company's Kiln Number 3 Stack*, Mullins Environmental Testing Co., Inc., Addison, TX, March 1980.

17. *Source Emissions Survey of Lone Star Industries, Inc.: Kilns 1, 2, and 3*, Mullins Environmental Testing Co., Inc., Addison, TX, June 1980.

18. *Source Emissions Survey of Lone Star Industries, Inc.*, Mullins Environmental Testing Co., Inc., Addison, TX, November 1981.

19. *Stack Emission Survey and Precipitator Efficiency Testing at Bonner Springs Plant*, Lone Star Industries, Inc., Houston, TX, November 1981.

20. *NSPS Particulate Emission Compliance Test: No. 8 Kiln*, Interpoll, Inc., Blaine, MN, March 1983.

21. *Annual Compliance Test: Mojave Plant*, Pape & Steiner Environmental Services, Bakersfield, CA, May 1983.

22. Sid Levine, "New Mojave Plant of California Portland Under Computer Control", *Pit & Quarry*, pp. 82-87, July 1983.

23. *Source Emissions Survey of Lehigh Portland Cement Company*, Mullins Environmental Testing Co., Inc., Addison, TX, August 1983.

24. *Annual Compliance Test: Mojave Plant*, Pape & Steiner Environmental Services, Bakersfield, CA, May 1984.

25. *Particulate Compliance Test: Lehigh Portland Cement Company*, CH2M Hill, Montgomery, AL, October 1984.

26. *Compliance Test Results: Particulate & Sulfur Oxide Emissions at Lehigh Portland Cement Company*, KVB, Inc., Irvine, CA, December 1984.

27. *Annual Compliance Test: Mojave Plant*, Pape & Steiner Environmental Services, Bakersfield, CA, May 1985.

28. *Stack Tests for Particulate, SO_2, NO_x and Visible Emissions at Lone Star Florida Holding, Inc.*, South Florida Environmental Services, Inc., West Palm Beach, FL, August 1985.

29. *Compliance Stack Test at Lone Star Florida/Pennsuco, Inc.*, South Florida Environmental Services, Inc., West Palm Beach, FL, July 1981.

30. *Preliminary Stack Test at Lone Star Florida/Pennsuco, Inc.*, South Florida Environmental Services, Inc., West Palm Beach, FL, July 1981.

31. *Quarterly Testing for Lone Star Cement at Davensport, California*, Pape & Steiner Environmental Services, Bakersfield, CA, September 1985.

32. *Stack Sampling at Trinity Division of General Portland, Fort Worth, Texas*, Texas Air Control Board, Fort Worth, TX, July 1976.

33. *Stack Sampling at General Portland Cement, Trinity Division, Fort Worth, Texas*, Texas Air Control Board, Fort Worth, TX, January 1977.

34. *Stack Sampling at General Portland, Inc., Trinity Division, Fort Worth, Texas*, Texas Air Control Board, Fort Worth, TX, February 1979.

35. Written Communication from David S. Cahn, CalMat Co., El Monte, CA, to Frank Noonan, U.S. Environmental Protection Agency, Research Triangle Park, NC, June 2, 1987.

36. *Technical Report on the Demonstration of the Feasibility of NO_x Emissions Reduction at Riverside Cement Company, Crestmore Plant (Parts I-V)*, Riverside Cement Company, Riverside, CA, and Quantitative Applications, Stone Mountain, GA, January 1986.

37. *Emission Study of the Cement Kiln No. 20 Baghouse Collector at the Alpena Plant, Great Lakes Division, Lafarge Corporation*, Clayton Environmental Consultants, Inc., Novi, MI, March 1989.

38. *Emission Testing of Dust Collectors on Kiln No. 1 at Lafarge Corporation, Paulding, Ohio*, Clayton Environmental Consultants, Inc., Novi, MI, July 1989.

39. *Test Report of Kiln Exhaust Emissions from Southwestern Portland Cement Company, Kilns Nos. 5 and 8 at the Victorville Plant and Kiln No. 1 at the Black Mountain Plant*, Truesdail Laboratories, Inc., Los Angeles, CA, September 1980.

40. *Baseline and Solvent Fuels Stack Emissions Test at Alpha Portland Cement Company in Cementon, New York*, Energy & Resource Recovery Corp., Albany, NY, January 1982.

41. *Lehigh Portland Cement Company White Kiln Coke Conversion Emission Compliance Report*, Tenerex Corporation, Friendswood, TX, December 1985.

42. *Stationary Source Sampling Report of Lone Star Industries, New Orleans, Louisiana*, Entropy Environmentalists, Inc., Research Triangle Park, NC, May 1982.

43. *Stationary Source Sampling Report of Lone Star Industries, New Orleans, Louisiana*, Entropy Environmentalists, Inc., Research Triangle Park, NC, May 1982.

44. *Source Emissions Survey of Kiln No. 1 at Lone Star Industries, Inc., New Orleans, Louisiana*, Mullins Environmental Testing Company, Inc., Addison, TX, March 1984.

45. Written Communication from Don Sinkular, Gifford-Hill Cement Company of Texas, Midlothian, TX, to John Croom, Quantitative Applications, Inc., Stone Mountain, GA, December 18, 1989.

46. Written Communication from Gerald Young, St. Mary's Peerless Cement, Detroit, MI, to John Croom, Quantitative Applications, Inc., Stone Mountain, GA, December 13, 1989.

47. Anonymous Written Communication, Truesdail Laboratories, Incorporated, Results of tests conducted on Southwestern Portland Cement, Black Mountain, California, Kilns 5 and 8, October 9, 1980.

48. Written Communication from Douglas MacIver, Southwestern Portland Cement Company, Victorville, CA, to Walter Mook, San Bernadino County Air Pollution Control District, San Bernadino, CA, August 22, 1980.

49. Written Communication from Richard Cooke, Ash Grove Cement West, Inc., Durkee, OR, to Frank Noonan, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 13, 1987.

50. Written Communication from Stan Cramer, Calveras Cement Company, Redding, CA, to Frank Noonan, U.S. Environmental Protection Agency, Research Triangle Park, NC, May 13, 1987.

51. *Source Emissions Survey of Texas Cement Company of Buda, Texas*, Mullins Environmental Testing Co., Inc., Addison, TX, September 1986.

52. *Determination of Particulate and Sulfur Dioxide Emissions from the Kiln and Alkali Baghouse Stacks at Southwestern Portland Cement Company*, Pollution Control Science, Inc., Miamisburg, OH, June 1986.

53. Written Communication from Doug MacIver, Southwestern Portland Cement Company, Victorville, CA, to John Croom, Quantitative Applications, Inc., Stone Mountain, GA, October 23, 1989.

54. *Source Emissions Survey of Southwestern Portland Cement Company, KOSMOS Cement Division*, MetCo Environmental, Dallas, TX, June 1989.

55. Written Communication from John Mummert, Southwestern Portland Cement Company, Amarillo, TX, to Bill Stewart, Texas Air Control Board, Austin, TX, April 14, 1983.

56. Written Communication from Stephen Sheridan, Ash Grove Cement West, Inc., Portland, OR, to John Croom, Quantitative Applications, Inc., Stone Mountain, GA, January 15, 1980.

57. Written Communication from David Cahn, CalMat Co., Los Angeles, CA, to John Croom, Quantitative Applications, Inc., Stone Mountain, GA, December 18, 1989.

58. *Source Emissions Compliance Test Report on the Kiln Stack at Marquette Cement Manufacturing Company, Cape Girardeau, Missouri*, Performance Testing & Consultants, Inc., Kansas City, MO, February 1982.

59. *Assessment of Sulfur Levels at Lone Star Industries in Cape Girardeau, Missouri,* KVB, Elmsford, NY, January 1984.

60. Written Communication from Douglas MacIver, Southwestern Portland Cement Company, Nephi, UT, to Brent Bradford, Utah Air Conservation Committee, Salt Lake City, UT, July 13, 1984.

61. *Performance Guarantee Testing at Southwestern Portland Cement,* Pape & Steiner Environmental Services, Bakersfield, CA, February 1985.

62. *Compliance Testing at Southwestern Portland Cement,* Pape & Steiner Environmental Services, Bakersfield, CA, April 1985.

63. *Emission Tests on Quarry Plant No. 2 Kiln at Southwestern Portland Cement,* Pape & Steiner Environmental Services, Bakersfield, CA, March 1987.

64. *Emission Tests on the No. 2 Kiln Baghouse at Southwestern Portland Cement,* Pape & Steiner Environmental Services, Bakersfield, CA, April 1987.

65. *Emissions Testing of a Precalciner Cement Kiln at Louisville, Nebraska,* U.S. Environmental Protection Agency, Washington, D.C., November 1990.

66. *Emissions Testing of a Wet Cement Kiln at Hannibal, Missouri,* U.S. Environmental Protection Agency, Washington, D.C., December 1990.

67. *Compliance Stack Test on Kiln No. 3 at Lone Star Florida, Inc.*, South Florida Environmental Services, Inc., Belle Glade, FL, July 1980.

68. *Compliance Stack Test of Cooler No. 3 at Lone Star Florida, Inc.*, South Florida Environmental Services, Inc., Belle Glade, FL, July 1980.

69. *Stack Emissions Survey of Lone Star Industries, Inc., Portland Cement Plant at Maryneal, Texas*, Ecology Audits, Inc., Dallas, TX, September 1979.

70. *Visible Emission Testing at Four Portland Cement Plants*, EPA Report No. 75-CEM-1, U.S. Environmental Protection Agency, Research Triangle Park, NC, August 1974.

71. *Field Data Source Test of Lone Star Industries at Davenport, California*, Chemecology Corp., Pittsburg, CA, August 1983.

72. *NSPS Particulate Emission Compliance Test on the No. 8 Kiln at the Lehigh Portland Cement Plant in Mason City, Iowa*, Interpoll, Inc., Circle Pines, MN, July 1983.

73. *Field Data Source Test at Lone Star Industries, Davenport, California,* Chemecology, CA, May 1982.

74. *Emissions Testing Report Conducted at Kaiser Cement, Coupertino, California, for Kaiser Cement, Walnut Creek, California*, TMA Thermo Analytical, Inc., Richmond, CA, April 30, 1990.

75. *Source Emissions Survey of Boxcrow Cement Company Kiln Stack, Midlothian, Texas, TACB Permit C-8996, Volume I, Metco Environmental,* October 1991.

76. *Certification of Compliance Stack Emission Test Program at Lone Star Industries, Inc., Cape Girardeau, Missouri, April & June 1992*, Air Pollution Characterization and Control, Ltd., Tolland, CT, January 1993.

77. *Source Emissions Survey of Essrock Materials, Inc., Eastern Division Cement Group, Kilns Number 1 and 2 Stack, Frederick, Maryland, Volume I (Draft)*, Metco Environmental, Addison, TX, November 1991.

78. M. Branscome et al., *Evaluation of Waste Combustion in a Dry-Process Cement Kiln at Lone Star Industries, Oglesby, Illinois*, Research Triangle Institute, Research Triangle Park, NC, December 1984.

79. J. Kinsey, *Lime and Cement Industry Particulate Emissions: Source Category Report, Volume II., Cement Industry*, EPA-600/7-87-007, U.S. Environmental Protection Agency, Research Triangle Park, NC, February 1987.

80. Dellinger, H.B., D.W. Pershing, and A.F. Sarofim. *Evaluation of the Origin, Emissions and Control of Organic and Metal Compounds from Cement Kilns Fired with Hazardous Wastes*. Science Advisory Board on Cement Kiln Recycling. June 1993.

81. Written communication from Robert W. Crolius, Portland Cement Association, to Ron Myers, U. S. Environmental Protection Agency, Research Triangle Park, NC. March 11, 1992.

5.0 PROPOSED AP-42 SECTION 11.6

A proposed revision of the existing AP-42 Section 8.6, Portland Cement Manufacturing, is presented in the following pages as it would appear in the document.

APPENDIX A

DERIVATION OF CRITERIA POLLUTANT EMISSION FACTORS FOR PORTLAND CEMENT KILNS

APPENDIX A.

DERIVATION OF CRITERIA POLLUTANT EMISSION FACTORS FOR PORTLAND CEMENT KILNS

The following tables present the derivation of the average emission factors for emissions of criteria pollutants (PM, SO_2, NO_x, CO, TOC, and CO_2) from portland cement kilns, as presented in Tables 4-11 to 4-14 of this background report and Tables 11.6-1, 11.6-2, 11.6-5, and 11.6-7 of the AP-42 section. The data for wet process kilns, dry process kilns, preheater kilns, and preheater/precalciner kilns are presented in Tables A-1, A-2, A-3, and A-4, respectively. These tables include the results from each test report from which an emission factor could be developed for the pollutants listed above. For each test, the tables list the type of control (Column 2), average emission factor in kg/Mg and lb/ton (Columns 3 and 4), the data rating (Column 5), and the reference number (Column 9) as designated in Chapter 4 of this background report. The emission factors that were used to calculate the average emission factor for a specific pollutant and type of kiln are listed in the second set of emission factors (Columns 6 and 7) in the tables. The ratings (Column 8) assigned to these average emission factors also are indicated in the tables. The comment column in the tables indicates if the test data were discarded.

For wet process and preheater/precalciner kilns, data were available (and emission factors were developed) for multiple tests on some kilns. In such cases, the kilns were arbitrarily labeled (A, B, C, etc. [Column 1]), the average emission factor for each of those kilns was calculated, and an average data rating was assigned. These kiln-specific average emission factors then were used to determine the overall average emission factor for a specific pollutant, control device, and kiln type.