Emission Factor Documentation for AP-42
Section 9.9.1

Grain Elevators and Grain Processing Plants

Final Report

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

EPA Purchase Order No. 8D-1933-NANX

MRI Project No. 4945

May 1998

Emission Factor Documentation for AP-42 Section 9.9.1

Grain Elevators and Grain Processing Plants

Final Report

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

Attn: Mr. Dallas Safriet (MD-14)

EPA Purchase Order No. 8D-1933-NANX

MRI Project No. 4945

May 1998

NOTICE

The information in this document has been funded wholly or in part by the U. S. Environmental Protection Agency under Contract No. 68-D2-0159 and Purchase Order No. 8D-1933-NANX to Midwest Research Institute. It has been reviewed by the Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, and has been approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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. 4604-04 and Purchase Order No. 8D-1933-NANX. Mr. Dallas Safriet was the requester of the work.

Approved for:

MIDWEST RESEARCH INSTITUTE

Roy Neulicht
Program Manager
Environmental Engineering Department

Jeff Shular
Director, Environmental Engineering
Department

May 1998

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Page

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

EMISSION FACTOR DOCUMENTATION FOR AP-42 SECTION 9.9.1
Grain Elevators and Grain Processing Plants

1. INTRODUCTION

The document *Compilation of Air Pollutant Emission 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 is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. Emission factors usually are expressed as the weight of pollutant divided by the unit weight, volume, distance, or duration of the activity that emits the pollutant. The emission factors presented in AP-42 may be appropriate to use in a number of situations, such as making source-specific emission estimates for areawide inventories for dispersion modeling, developing control strategies, screening sources for compliance purposes, establishing operating permit fees, and making permit applicability determinations. The purpose of this report is to provide background information from test reports and other information to support revisions to AP-42 Section 9.9.1, Grain Elevators and Grain Processing Plants.

This background report consists of five sections. Section 1 includes the introduction to the report. Section 2 gives a description of the grain elevator and grain processing industries. It includes a characterization of the industry, a description of the different process operations, a characterization of emission sources and pollutants emitted, and a description of the technology used to control emissions resulting from these sources. Section 3 is a review of emission data collection (and emission measurement) 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 how the revised AP-42 section was developed. It includes the review of specific data sets, a description of how candidate emission factors were developed, and a summary of changes to the AP-42 section. Section 5 presents the AP-42 Section 9.9.1, Grain Elevators and Grain Processing Plants. Supporting documentation and calculations for emission factor development are provided in the appendices.

2. INDUSTRY DESCRIPTION

This section of the report is divided into four major subsections. The first subsection (2.1) of this chapter characterizes the industry and includes a general overview of grains and their uses, data on grain elevators (including their number, location, and capacity), and a discussion of grain milling and processing industries, including flour mills, rice mills, dry corn mills, and animal feed manufacturing facilities. The second subsection (2.2) describes the steps involved in grain handling and processing in grain elevators and processing facilities. The third subsection (2.3) describes air pollutant emissions from sources in the grain elevator and grain processing industries. The fourth subsection (2.4) describes the emission control technologies typically applied to air emission sources in the grain elevator and grain processing industries.

2.1 INDUSTRY CHARACTERIZATION

Industry characterization provides background information on various grains and oilseeds or feeds and their uses. The subsequent subsections characterize the grain elevator industry and the grain processing industries.

2.1.1 Grains and Their Uses[1-12]

Grains are produced from a very large family of flowering plants referred to as grasses. Grains include corn, wheat, rice, oats, rye, barley, and grain sorghum (or milo), all of which are commonly referred to as cereal grains or cereals. Soybeans, lentils, cottonseed, and alfalfa are not grains, but are, however, classified under the category of oilseeds or feeds.

Grain seeds, or kernels, are the focus of grain production, harvesting, and processing. The kernels of the various grains are generally similar, consisting of primarily germ, endosperm, a bran coat, and hull. During processing, the hull, and frequently the outer bran, the germ, and the endosperm are separated from each other. Each of these components is used to produce various meals, feeds, and other products. Figure 2-1 illustrates the various uses of the three materials obtained from one grain, corn. The husk or hull can be used or mixed with other ingredients to provide a source of bran in cattle or livestock feed. The germ, or inner portion of the kernel, can be used to produce meal or various corn oil products. The endosperm can be processed to provide meal, cereals, livestock feed (for hogs, cattle, sheep, and poultry), or a number of starch and sugar products. Corn may also be used to produce ethyl alcohol (ethanol), which can be used as a gasoline additive for motor vehicle fuel or for the production of numerous industrial chemicals.

Other grains commonly grown and processed in the United States provide the following products:

- Wheat is often differentiated into one of its three most common species. Common !wheat includes winter and spring wheat, and its principal use is for production of bread. Club wheat, similar to common wheat but not bearded, is also a source for flour and food products. Durum wheat has harder kernels and, when ground, holds together well for use in pastas. The wheat germ may also be used for human consumption and in livestock feeds.

- Rice, which produces a higher yield per acre than any other grain with the exception of corn, is primarily used as a food grain for human consumption.

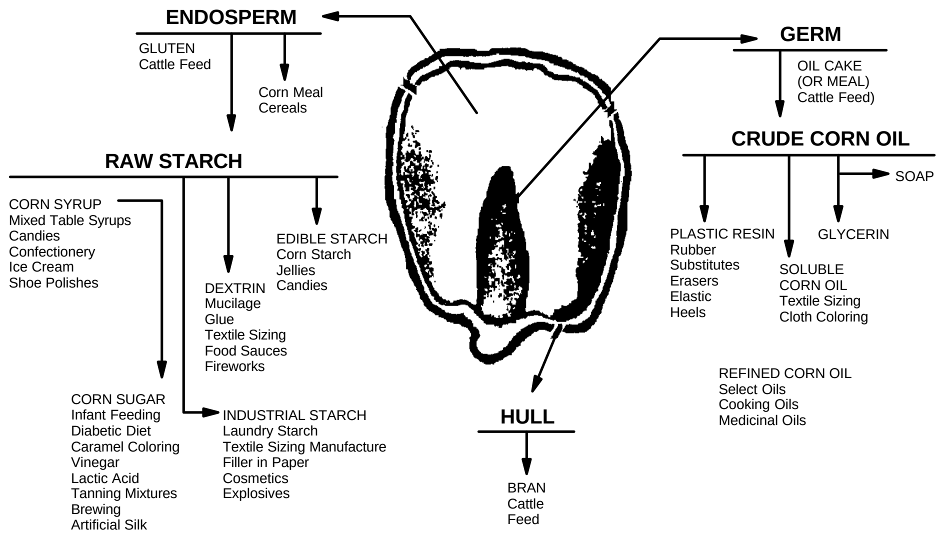

Figure 2-1. Various uses of corn.[6]

- Oats are predominantly used as food for livestock, with only a small fraction used for human consumption.

- Rye, like wheat, is principally used as a bread grain, or secondarily as livestock feed.

- Barley is predominantly used to produce formulated animal feeds and also provides a source of malt for brewing beer. Only a small fraction is used for human consumption.

- Sorghum is used primarily for animal feed or pasture.

Grains are generally grown in the midwestern United States, as reflected in Table 2-1, which shows the acreage in farms for each state. Corn production occurs in nearly every state, but the major growing area is a belt from Ohio through Indiana, Illinois, Iowa, and Nebraska (and adjacent areas in neighboring States). Wheat and rye are primarily grown in the same states, and also in a north-to-south belt from Texas to North Dakota. Barley is principally harvested in the northern plains states, California, and to a lesser degree in the Midwest and Northwest. Sorghum and oats are grown most commonly in a belt extending from Texas to the Great Lakes region.

2.1.2 Grain Elevators[13-16]

Grain elevators facilitate the movement of grain from the farmer to the processor or exporter. Operations at most grain elevators are similar, but elevators are generally divided into functional classifications according to their size, source of grain, and destination of shipments. The U.S. Department of Agriculture identifies two classes of elevators, country and terminal, on the basis that terminal elevators furnish USDA official weights under the supervision of a state inspector.

TABLE 2-1. UNITED STATES ACREAGE IN FARMS, 1996[a]

State	1996 land in farms, 1,000 acres	State	1996 land in farms, 1,000 acres
Texas	127,000	Tennessee	11,800
Montana	59,700	Utah	11,000
Kansas	47,800	Michigan	10,600
Nebraska	47,000	Florida	10,300
South Dakota	44,000	Alabama	9,800
New Mexico	43,700	North Carolina	9,200
North Dakota	40,300	Nevada	8,800
Arizona	35,400	Louisiana	8,700
Wyoming	34,600	Virginia	8,600
Oklahoma	34,000	New York	7,700
Iowa	33,200	Pennsylvania	7,700
Colorado	32,500	South Carolina	5,000
California	30,000	West Virginia	3,700
Missouri	30,000	Maryland	2,100
Minnesota	29,800	Hawaii	1,590
Illinois	28,100	Vermont	1,350
Oregon	17,500	Maine	1,340
Wisconsin	16,800	Alaska	920
Indiana	15,900	New Jersey	840
Washington	15,700	Massachusetts	570
Ohio	15,100	Delaware	565
Arkansas	15,000	New Hampshire	430
Kentucky	14,000	Connecticut	380
Idaho	13,500	Rhode Island	63
Mississippi	12,600		
Georgia	11,800		
		U.S. TOTAL	968,048

[a]Reference 11.

The definitions generally used are less precise, classifying country elevators as those that receive the bulk of their grain directly from the farm. These elevators are usually of a smaller size than terminal elevators. Terminal elevators are defined as those that receive grain from country elevators and ship grain directly to a processor or exporter. Terminal elevators are often classified further as either port or inland terminals. An intermediate class of elevators, subterminals, receive the bulk of their shipments from country elevators but still receive a significant amount of grain from farms. Subterminal elevators may ship grain both to terminal elevators and directly to processors.

Regardless of whether the elevator is a country or terminal, there are two basic types of elevator design: traditional and modern. Traditional grain elevators are typically designed so the majority of the grain handling equipment (e.g., conveyors, legs, scales, cleaners) are located inside a building or structure, normally referred to as a headhouse. The traditional elevator often employs belt conveyors with a movable tripper to transfer the grain to storage in concrete or steel silos. The belt and tripper combination is located above the silos in an enclosed structure called the gallery or bin deck. Grain is often transported from storage using belt conveyors located in an enclosed tunnel beneath the silos. Particulate emissions inside the elevator structure may be controlled using equipment such as cyclones, fabric filters, dust covers, or belt wipers; grain may be oil treated to reduce emissions. Controls are often used at unloading and loading areas and may include cyclones, fabric filters, baffles in unloading pits, choke unloading, and use of deadboxes or specially designed spouts for grain loading. The operations of traditional elevators are described in more detail in Section 2.2.1. Traditional elevator design is generally associated with facilities built prior to 1980.

Country and terminal elevators built in recent years have moved away from the design of the traditional elevators. The basic operations performed at the elevators are the same; only the elevator design has changed. Most modern elevators have eliminated the enclosed headhouse and gallery (bin decks). They employ a more open structural design, which includes locating some equipment such as legs, conveyors, cleaners, and scales, outside of an enclosed structure. In some cases, cleaners and screens may be located in separate buildings. The grain is moved from the unloading area using enclosed belt or drag conveyors and, if feasible, the movable tripper has been replaced with enclosed distributors or turn-heads for direct spouting into storage bins and tanks. The modern elevators are also more automated, make more use of computers, and are less labor-intensive. Some traditional elevators have also been partially retrofitted or redesigned to incorporate enclosed outside legs, conveyors, cleaners, and other equipment. Other techniques used to reduce emissions include deepening the trough of the open-belt conveyors and slowing the conveyor speed, and increasing the size of leg belt buckets and slowing leg velocity. At loading and unloading areas of modern elevators, the controls cited above for traditional elevators can also be used to reduce emissions.

Statistics for the amount of grain produced in the United States in 1996 are shown in Table 2-2. A substantial portion of grain produced in the U.S. is handled through grain elevators. Data available on the number, size, and location of grain elevators are based on USDA information maintained on off-farm storage facilities. As of December 1996, a total of 10,717 elevators with a total capacity of 2.85×10^8 cubic meters (m^3) (8.09×10^9 bushels [bu]) were reported by USDA. The number and capacity of these elevators listed by EPA region and state is presented in Table 2-3. The average storage capacity of country elevators is about 2.1×10^4 m^3 (6×10^5 bu), and the average capacity of terminals is about 1.6×10^5 m^3 (4.4×10^6 bu). However, there is significant variation in country and terminal elevator capacities, with capacities in excess of 50 million bu in one terminal elevator. This capacity includes grains stored in bins, storage tanks, and warehouse-type facilities that have been added to the original facility.

TABLE 2-2. 1996 STATISTICS FOR GRAIN PRODUCED[a]

Grain	10^3 cubic meters	10^3 bushels	10^3 megagrams	10^3 tons
Wheat	80,409	2,281,763	62,099	68,309
Rye	318	9,016	229	252
Rice	Not provided	Not provided	7,771	8,548
Corn	327,501	9,293,435	236,064	259,670
Oats	5,470	155,225	2,253	2,478
Barley	13,985	396,851	8,640	9,504
Sorghum	28,297	802,974	20,396	22,436
TOTAL			337,452	371,197

[a]Reference 13.

TABLE 2-3. NUMBER AND LOCATION OF GRAIN ELEVATORS, 1996[a]

Location	No.	Capacity	
		1,000 m^3	1,000 bushels
Region I	29	285	8,080
Connecticut	NA	NA	NA
Massachusetts	NA	NA	NA
Maine	NA	NA	NA
New Hampshire	NA	NA	NA
Rhode Island	NA	NA	NA
Vermont	NA	NA	NA
Region II	99	1,521	43,150
New Jersey	20	88	2,490
New York	79	1,433	40,660
Region III	432	4,806	136,380
Delaware	21	821	23,310
Maryland	64	1,573	44,650
Pennsylvania	229	994	28,210
Virginia	118	1,417	40,210
Region IV	1,262	13,062	370,660
Alabama	102	1,066	30,250
Florida	33	346	9,820
Georgia	218	1,920	54,470
Kentucky	233	2,038	57,820
Mississippi	94	2,079	59,000
North Carolina	250	2,646	75,090
South Carolina	103	893	25,350
Tennessee	229	2,074	58,860
Region V	3,289	90,607	2,571,140
Illinois	1,076	38,423	1,090,320
Indiana	455	12,126	344,110
Minnesota	522	16,996	482,300
Michigan	292	5,145	146,000
Ohio	522	11,754	333,530
Wisconsin	422	6,163	174,880

TABLE 2-3. (continued)

Location	No.	Capacity	
		1,000 m^3	1,000 bushels
Region VI	1,285	44,005	1,248,730
Arkansas	200	7,346	208,450
Louisiana	63	3,290	93,360
New Mexico	27	561	15,920
Oklahoma	295	8,713	247,260
Texas	700	24,095	683,740
Region VII	2,552	92,351	2,620,630
Iowa	623	34,691	984,420
Kansas	874	26,850	761,920
Missouri	508	8,245	233,970
Nebraska	547	22,565	640,320
Region VIII	1,071	20,472	580,940
Colorado	134	4,146	117,660
Montana	152	2,119	60,120
North Dakota	438	8,840	250,850
South Dakota	292	4,351	123,470
Utah	35	702	19,920
Wyoming	20	314	8,920
Region IX	197	4,185	118,770
Arizona	31	811	23,020
California	166	3,374	95,750
Region X	491	13,598	385,880
Idaho	79	3,824	108,510
Oregon	124	2,379	67,520
Washington	288	7,395	209,850
Unallocated[b]			
Nevada/West Virginia	10	33	930
U.S. TOTAL	10,717	284,926	8,085,290

[a]Reference 14. NA = not available.
[b]Combined figures provided for Nevada (Region IX) and West Virginia (Region III).

Another measure of "size" of grain elevators is the annual throughput (i.e., the total amount of grain handled by an elevator during a year). The ratio of grain handled to capacity varies between types of elevators and at individual elevators from year to year. The variation at country elevators is primarily dependent upon the amount of grain harvested in the area during a particular year and upon the accessibility of shipping capacity to the elevator. The volume of grain handled by inland terminals is dependent upon quantity of grain harvested, movement of grain, quantity of exports, and marketing channels used by grain merchants and processors as well as transportation and geographic factors.[15]

Both country and terminal elevators are classified in Standard Industrial Classification (SIC) Code 5153. No other industries are classified within this SIC code.

2.1.3 Grain Milling and Processing Industry[17-22]

Grain milling and processing industries encompass those facilities that use grains (wheat, corn, rice, oats, sorghum, barley, and rye) as the primary feedstock and produce final or intermediate grain products. These facilities include flour mills (primarily wheat flour mills but also oat and rye mills), rice mills, dry corn mills, and animal feed mills. (Note that in earlier AP-42 editions, soybean processing and corn wet milling were included in this AP-42 section. In this edition, soybean processing has been moved to Section 9.11.1, Vegetable Oil Processing, and corn wet milling has been moved to Section 9.9.7, Corn Wet Milling.)

Flour milling operations are classified in SIC Code 2041, Flour and Other Grain Mill Products, which includes establishments primarily engaged in milling flour or meal from grain except rice. Facilities within this category are engaged primarily in wheat flour milling, but the category also includes buckwheat, durum, corn, graham (i.e., unbolted wheat flour), oat, and rye flour production as well as corn meal production via dry corn milling. As of 1992, the U.S. Department of Commerce estimates that there were 365 facilities in the United States that produced flour and other milled grain products.[18] A 1992 publication states that there are 205 wheat flour mills, 23 durum wheat mills, and 12 rye mills in the United States.[17] Table 2-4 lists the number of facilities, by state, for those states with more than 100 employees involved in grain milling.

Rice milling operations are classified under SIC Code 2044, Rice Milling. Establishments within this SIC code process raw rice to obtain brown rice, milled rice (including polished rice), rice flour, rice meal, and rice bran. In 1992, there were 53 rice mills in the United States.[18] States with the largest numbers of plants were Arkansas (15), California (11), Louisiana (8), Texas (8), and Mississippi (3).

Animal feed manufacturing facilities process grains, grain milling byproducts, oil extraction byproducts, and nongrain ingredients to produce formula feeds for livestock and poultry. These facilities are included as a part of SIC Code 2048, Prepared Feeds and Feed Ingredients for Animals and Fowls, Except Dogs and Cats. This SIC code is quite broad. In addition to grain processing facilities, it includes facilities that process hay, alfalfa, animal byproducts, feed supplements, and feed concentrates used to produce animal feed. This section of AP-42 considers only those facilities that process grain to produce animal feed.

Because both the feed stocks and products for this industry are so diverse, different sources of information on the number of facilities in the industry show substantial discrepancies. The latest information presented in the Census of Manufactures indicates that in 1992 a total of 1,714 facilities classified as feed manufacturing facilities under SIC Code 2048 were operating in the United States.[18] Table 2-4 shows the distribution of these facilities among the larger producing states. However, a 1985 study of the industry reported that the commercial feed industry included about 3,000 primary feed manufacturing facilities and 10,000 secondary manufacturing facilities.[21] (Primary feed manufacturing is defined as "the processing and mixing of individual feed ingredients, sometimes with the addition of a premix at a rate of less than 100 pounds per ton (lb/ton) of finished feed." Secondary feed manufacturing is defined as "the processing and mixing of one or more ingredients with formula feed supplements.") Information supplied

TABLE 2-4. GRAIN HANDLING AND PROCESSING FACILITIES IN THE UNITED STATES, 1992[a,b]

Flour and other grain milling		Animal feed manufacturing[c]	
State	No. of facilities	State	No. of facilities
California	29	Iowa	117
Pennsylvania	26	California	110
North Carolina	23	Texas	102
Kansas	22	Pennsylvania	89
New York	20	Wisconsin	85
Minnesota	18	Illinois	83
Texas	18	Nebraska	79
Illinois	14	North Carolina	72
Indiana	14	Minnesota	68
Missouri	13	Georgia	59
Virginia	12	Kansas	57
Michigan	11	Arkansas	56
Ohio	11	Missouri	56
Washington	10	Ohio	51
Iowa	9	New York	49
Tennessee	9	Indiana	47
Utah	9	Alabama	46
Georgia	8	Oklahoma	38
Wisconsin	8	Florida	35
Colorado	6	Colorado	34
Nebraska	6	Washington	33
Florida	5	Virginia	30
Kentucky	5	Mississippi	29
Oklahoma	5	Kentucky	27
Maryland	3	Michigan	26
Montana	3	Tennessee	26
Oregon	3	Louisiana	22
North Dakota	2	Oregon	20
Hawaii	1		
U.S. TOTAL	365	U.S. TOTAL	1,714

[a]Only States with more than 100 employees within the SIC code listed.
[b]Reference 18.
[c]Only States with more than 20 facilities listed.

by the American Feed Industry Association (AFIA) indicated that, in 1995, more than 106.1 x 10^6 megagrams (Mg) (116.7 x 10^6 tons) of primary feed were manufactured by an estimated 1,800 registered and 4,000 nonregistered primary feed mills; in 1995, there were 5,500 secondary or custom mix plants.[22] Table 2-5 shows estimates of the primary feed production by region of the country developed by the AFIA for 1995.

TABLE 2-5. PRIMARY FEED PRODUCTION BY REGION: 1995[a]

	Primary feed production		
Region	10^6 Mg	10^6 tons	Percent
Northeast	8.85	9.73	8.3
Lake States	7.69	8.46	7.2
Corn Belt	17.20	18.92	16.2
Northern Plains	6.96	7.66	6.6
Appalachian	12.00	13.20	11.3
Southeast	16.20	17.82	15.3
Delta States	11.87	13.06	11.2
Southern Plains	13.43	14.77	12.7
Mountain	4.76	5.23	4.5
Pacific	7.09	7.80	6.7
United States	106.05	116.65	

[a]Source: Reference 22.

2.2 PROCESS DESCRIPTION

In this section, the grain handling and processing steps in grain elevators and grain processing facilities are described. A glossary of terms relating to grain milling is provided in Appendix A to aid the reader in understanding the processes.

2.2.1 Grain Elevators[12,15,23-25]

Operations at most grain elevators are similar, but elevators are generally divided into three functional classifications according to their size, source of grain, and destination of shipments. Country elevators are usually smaller, receive their grain primarily from farms by truck, and transport grain primarily by truck or rail to terminal elevators. The grain received at a country elevator comes primarily from farms within a 16- to 19-kilometer (km) (10- 12-mile [mi]) radius. Country elevators generally receive grain by trucks ranging in size from 11 to 35 m^3 (300 to 1,000 bu). Inland terminal elevators receive grain primarily from country elevators and ship grain, primarily by rail, directly to processors or to a port terminal. Port terminals are generally the largest elevators. They receive grain primarily by rail or barge from inland terminals and transport grain by rail, barge, or ship.

A grain elevator normally consists of a series of upright concrete or steel bins, wooden bins, and/or flat storage areas depending on the individual facility. Country elevators are usually designed to make maximum use of gravity flow in order to simplify the operations and minimize the use of mechanical equipment. Because of the large storage capacity and high grain-handling rates in terminal elevators, belt conveyors are generally used to move grain in these elevators. However, drag conveyors, augers, and direct spouting also may be used, particularly in newer elevators. Figure 2-2 identifies the major process operations at a grain elevator and also identifies potential PM emission sources; however, there is great diversity in the physical configuration of different elevators including the number of elevator legs and headhouse systems. In addition, many process vents are tied to ventilation systems and exhausted to air pollution control systems; the particular configuration of the ventilation system varies widely. Typical grain elevator process operations are discussed in the paragraphs which follow. The potential emission sources are discussed in Section 2.3.1.

After weigh-in, trucks are driven into an unloading station which is often a drive-through tunnel in the center of the elevator, or a shed located alongside the elevator. An elevator may have one or more of these stations. At country elevators, straight-bottom trucks are unloaded either by hydraulically lifting the dump bed, by lifting the front end of the truck with an overhead system, or by lifting the truck on a hydraulic platform. Grain flows out a gate in the back of the truck and falls through a grating into the receiving pit hopper. After unloading, trucks are reweighed to determine the quantity of grain received. Increasingly, grain received at country elevators is delivered in hopper-bottom (gondola) trucks. These trucks are positioned over the receiving pit grates and are unloaded from gates in the bottom of the truck. The truck receiving pit or hopper may have a capacity of 35 to 42 m^3 (1,000 to 1,200 bu), which is sufficient to handle the largest trucks. At terminal elevators, hopper railcars are unloaded over grates that are between the railroad tracks alongside the elevator. Sometimes railcar unloading areas are enclosed, but often they consist only of a roof over the unloading area. By opening the doors in the bottom of a hopper railcar, the grain flows through the grating into the receiving hopper.

In some cases, the receiving hopper system is large enough that the entire hopper truck or railcar can be unloaded without filling the receiving hopper. In other cases, the receiving hopper is comparatively small, quickly fills up, and blocks the bottom outlet of the hopper car. In the latter instance, grain flows out of the car only at the rate at which the grain is carried out of the receiving hopper. This latter type of unloading is termed "choke unloading" and can considerably reduce the quantity of dust generated in comparison to an unloading system in which all of the grain free falls into the receiving hopper.

Barge unloading at terminal elevators is usually accomplished by a specialized bucket elevator (marine "leg") that can be lowered into the holds of the barges. Cranes using clam shell buckets can also be used to unload grain into hoppers for discharge onto a conveyor belt. Once elevated to the top of the leg, the grain is discharged onto belt conveyors that carry the grain to the elevator proper. Barge unloading capacity at a terminal elevator can range from 630 to 2,600 m^3/hr (18,000 to 75,000 bu/hr), with an average unloading rate of 880 to 1,100 m^3/hr (25,000 to 30,000 bu/hr).

The grain dumped into the receiving hopper at a country elevator usually flows by gravity to the bottom (the boot) of the bucket elevator. In terminal elevators and in some country elevators, the grain is transported from the receiving hopper to the boot by means of belt, drag, or screw conveyors. From the boot, the grain is elevated by a leg (in this case the receiving leg) to the top of the elevator. Country elevators typically have only one or two receiving legs with a capacity ranging from 176 to 530 m^3/hr (5,000 to 15,000 bu/hr). Terminal elevator legs have an average capacity of 1,233 m^3/hr (35,000 bu/hr) or more, and a large elevator may have four or more legs.

At the top of the leg, the distributor, or some system of movable spouts, directs the grain either onto a gallery belt, into a scale garner for weighing and loadout, or into cleaning equipment. The section of the elevator that performs these functions is referred to as the "headhouse." Grain directed onto a gallery belt is conveyed across the top of the bins (gallery area) to a "tripper," which discharges the grain into the proper storage bin.

Grain received from the farm may contain various types of foreign material. Depending on market conditions, equipment availability, and local crop conditions, elevators may sometimes clean grain prior to sending the grain to storage bins. Various types of screens and aspiration systems (air "vacuuming" of

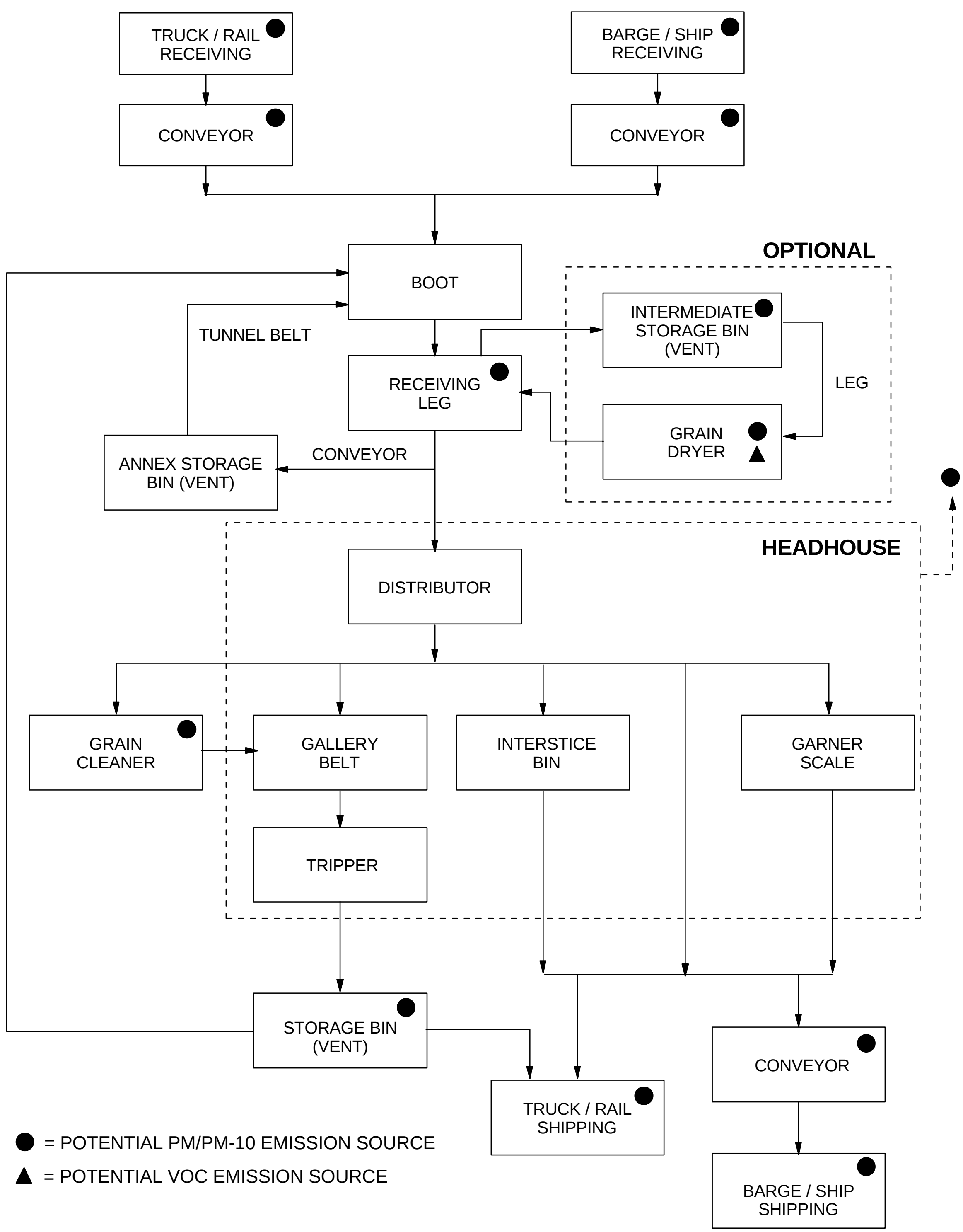

Figure 2-2. Major process operations at a grain elevator.

lightweight foreign material) can be used to clean the grain. The two basic types of cleaners are vibrating cleaners and enclosed stationary cleaners. Vibrating cleaners employ one or more inclined moving screens and are normally located within the elevator. In stationary cleaners, grain passes through a series of stationary screens of varying screen size; these units may be located either inside or outside the elevator.

Moving grain from the storage bins for loadout usually involves gravity flow back to the elevator boot, reelevation, and discharge through the distributor to the outloading point. The grain may be withdrawn from one or several storage bins via slide valves at the bottom of the bins. The grain falls by gravity from the storage bins into a tunnel belt leading back to the legs. The leg elevates the grain to the distributor head where it may be directed in one of three ways.

1. The grain may be directed to a scale hopper or garner, batch weighed in the scale, and then released through a loadout spout to a waiting truck or railroad car.

2. The grain may be directed to the truck loadout (or interstice) bin located directly above the drive-through tunnel or shed, where a waiting truck may be loaded at the same position where unloading takes place.

3. The grain may enter the distributor and fall directly through the loadout spout to a waiting truck or railcar.

An alternate method of loading is direct loading from individual bins by means of spouts that protrude from the bin walls. In this case, grain is distributed directly to either trucks or railcars or to the interstice bins above the drive-through tunnel for trucks. Loading of trucks at terminal elevators is similar to that at country elevators, except that grain is loaded at a faster rate. The loadout area is often partially enclosed, with openings at each end for truck arrival and departure. Hopper railcar loading is accomplished in a similar manner.

Barge- or ship-loading spouts associated with terminal elevators are generally located at barge or ship piers some distance from the elevator itself. In these cases, when the grain is released from the storage bins it may bypass the leg and fall onto the first of a series of conveyors that transport it to the barge- or ship-loading spouts.

Many elevators also include an annex storage facility. This annex may consist of several additional bins or a "flat-storage" tank or building for extra storage. Annex storage requires a gallery belt and "tripper" or some other form of conveyor to convey the grain from the discharge of the receiving leg to the annex storage bins, and a "tunnel belt," auger, or drag conveyor beneath the bins to convey the grain back to the boot of the elevator.

If the grain received at an elevator has a moisture content higher than that at which grain can be safely stored, it must be dried within a few days after receipt. Although many grains may require drying, corn usually necessitates the use of dryers. When the corn is received, it may contain 20 percent moisture or more, and must be dried to 13 percent to 14 percent moisture to be suitable for storage. Most country elevators are equipped with grain drying equipment. The four types of off-farm continuous-flow dryers currently used are cross-flow, concurrent flow, counterflow, and mixed-flow. Historically, cross-flow column-type dryers and mixed flow rack-type dryers have been used to dry grain at elevators. Figure 2-3 presents schematic diagrams for three types of units--a conventional cross-flow column dryer, a mixed-flow rack dryer, and a two-stage concurrent flow dryer. In the fourth type of unit--counterflow--the warm drying air is introduced at the bottom of the column and flows upward as the grain passes down the column.[12] The EPA's New Source Performance Standards (NSPS) for grain elevators established visible emission limits for grain dryers by requiring 0 percent opacity for emissions from column dryers with column plate perforations not to exceed 2.4 mm diameter (0.094 in.) or rack dryers with a screen filter not to exceed 50 mesh openings. Grain dryers generally require an additional leg to elevate wet grain from intermediate storage bins to the top of the dryer, and a means of conveying the dried grain from the dryer

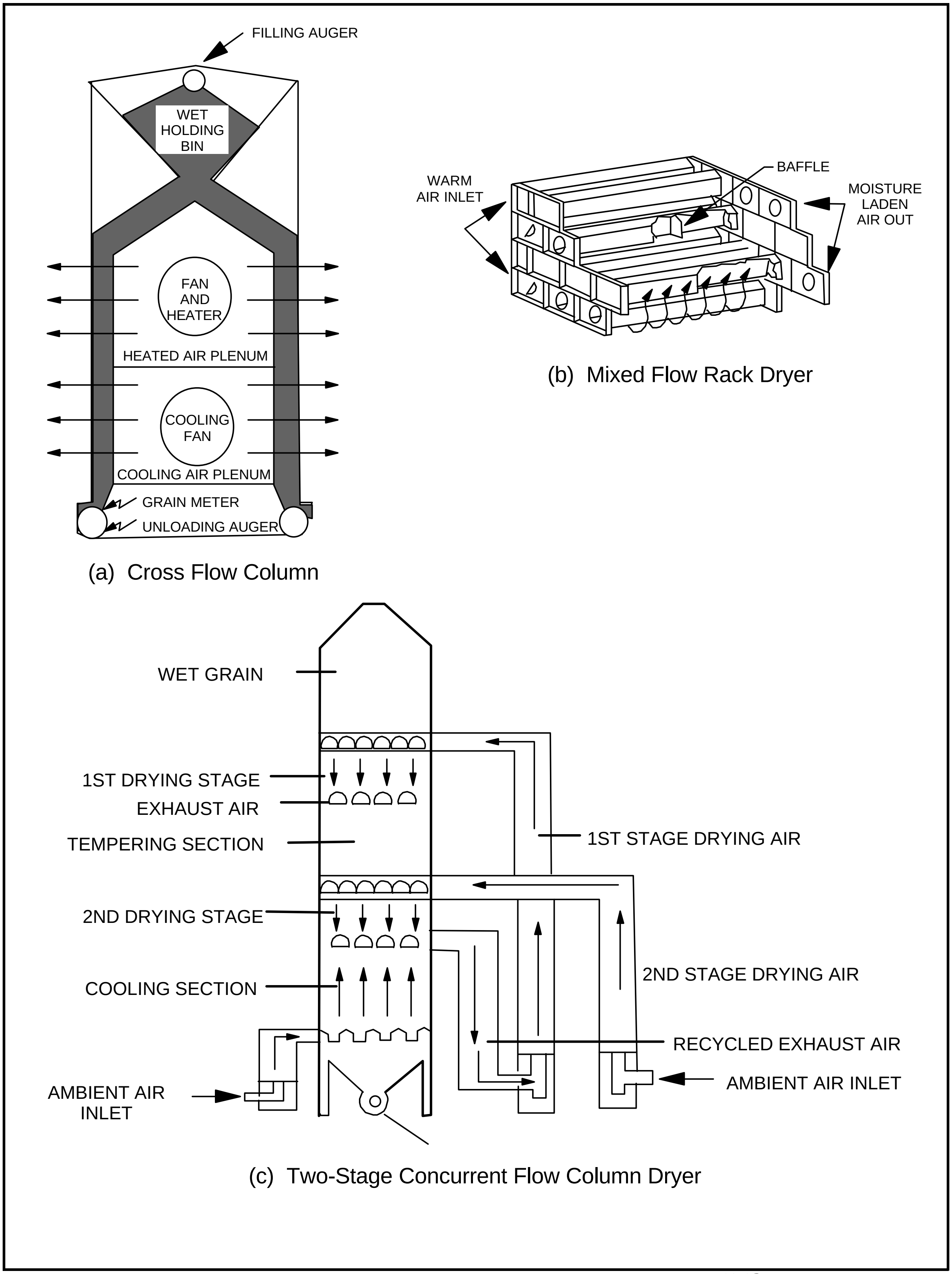

Figure 2-3. Schematic of rack- and column-type grain dryers.[12,23]

back to the primary leg for elevation to final storage. Grain dryers are available in a wide range of capacities, and the size installed is dependent upon the quantity of wet grain that is expected to be processed. A typical country elevator installation would likely have one dryer with a capacity of 17.6 to 35.0 m^3/hr (500 to 1,000 bu/hr).

Large elevators may need to cool stored grain periodically to preserve its quality. One historical method for accomplishing this cooling is by "turning" the grain during cold weather -- essentially elevating it to a height and allowing it to fall through cold ambient air. However, most modern terminal elevators employ in-bin aeration systems to control grain temperature and moisture content. With such systems cooling is accomplished by aerating the grain with cool air, which is either blown into or pulled through the grain mass by a system of ducts and fans tied to the storage bins.[25]

2.2.2 Grain Milling and Processing

The grain milling and processing industry comprises a large number of geographically dispersed facilities that have diverse feedstocks and produce a wide variety of products, such as flours, meals, oils, starches, syrups, and animal feeds. Because of the diversity of the industry, its scope is not well-defined. This discussion will be limited to those facilities that use grain as the primary raw material to produce either final products for human or animal consumption or intermediate products that are subsequently subjected to further processing. Although even this segment of the industry is quite diverse, it can be divided into five general segments based on similarity of processes and end products: (1) wheat and related dry grain milling, (2) oat milling, (3) rice milling, (4) corn dry milling, and (5) animal feed manufacturing. The processes used in each of these five segments are described in the subsections below.

2.2.2.1 Wheat and Related Dry Grain Milling[23,24] Wheat, durum wheat, and rye, are processed through a sequence of dry milling operations to produce flour, bran, middlings, and meal.[23] Although these processes do differ as a function of grain and end product, they have many similarities. Wheat flour milling is by far the predominant dry milling process and is described first, followed by discussions of durum wheat and rye milling processes.

The wheat flour milling process consists of five main steps:

1. Grain reception, preliminary cleaning, and storage.
2. Grain cleaning.
3. Tempering or conditioning.
4. Milling the grain into flour and its byproducts.
5. Storage and/or shipment of finished product.

Figure 2-4 presents a simplified diagram of a typical flour mill. Operations performed in each of these areas are discussed in the following paragraphs.

2.2.2.1.1 Wheat milling. Wheat arrives at mill elevators by truck, rail, barge, or ship, and is transferred by conveyors to the elevator headhouse. Often, preliminary cleaning occurs prior to wheat storage. After cleaning, the wheat is conveyed to storage bins. These receiving, handling, and storage operations are comparable to those found in grain elevators.

As grain is needed for milling, it is withdrawn from the storage elevator and conveyed to the mill area. In the mill area, wheat is first sent through a cleaning operation. This section of a mill is called the cleaning house. In the cleaning house, dust and smaller pieces of foreign material are removed from the grain. Impurities are removed from wheat based on size, specific gravity, shape, air resistance, and inherent differences in material (e.g., metal, stone). Equipment used to clean the wheat targets one or more of these differences to accomplish the cleaning.

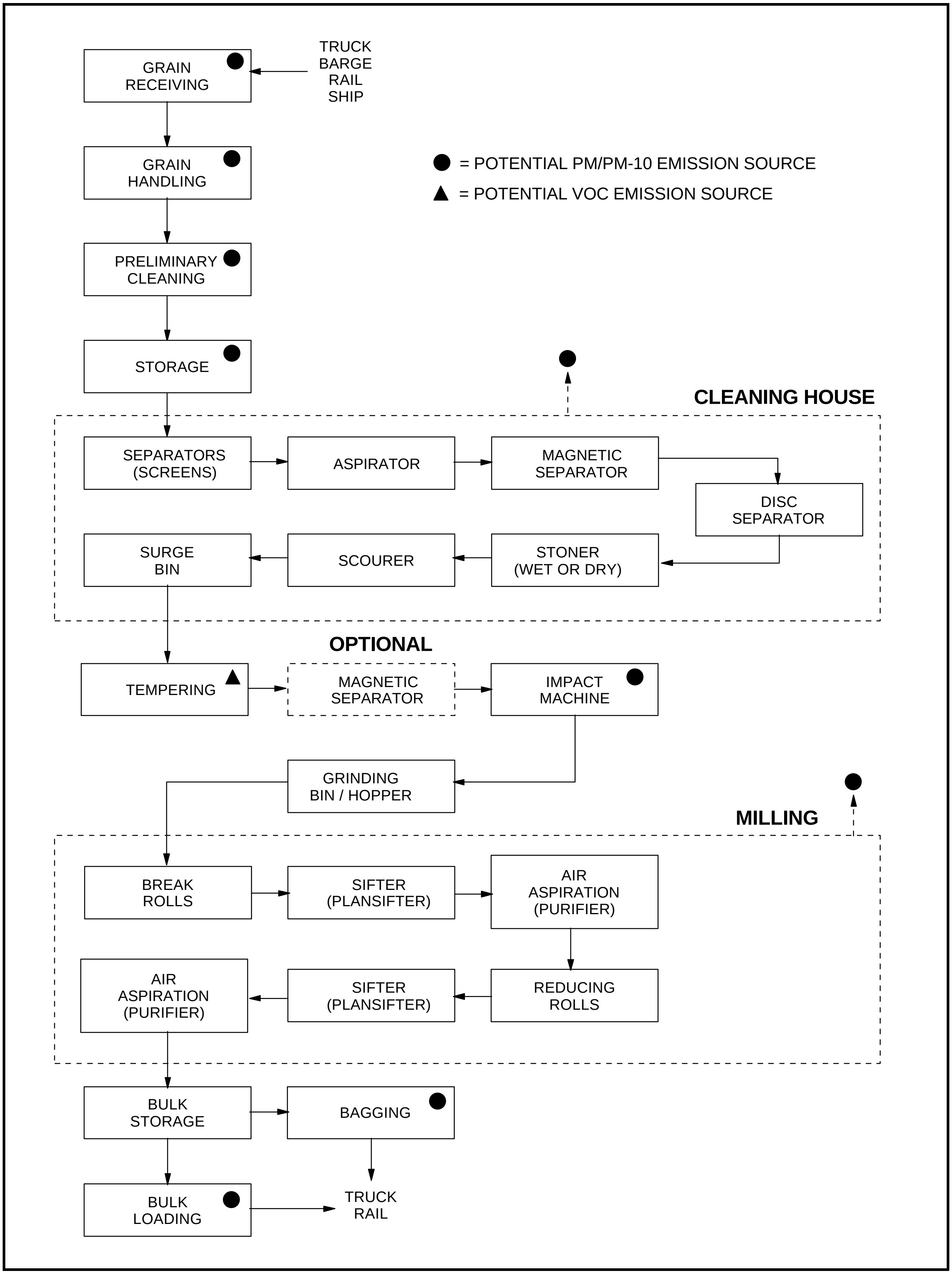

Figure 2-4. Simplified process flow diagram of a typical flour mill.

While placement and sequence of equipment varies from mill to mill and each mill may contain various material handling and storage operations between primary processing operations, the general flow scheme shown in Figure 2-4 will be used for subsequent discussion. The wheat first enters a separator, where it passes through a vibrating screen that removes bits of straw and other oversized foreign material and then through a second screen that removes undersized foreign material, such as seeds. Next, an aspirator uses air to lift off lighter impurities in the wheat. The stream of grain is directed across screens while air removes the dust and lighter particles. The stream of wheat then passes over a magnetic separator that removes iron and steel particles. The magnetic separator acts as a safeguard against nuts, bolts, rivets, or other pieces of metal which may break loose from harvesting, transportation, or handling machinery. Magnetic separators are used at many different points in a mill, especially prior to wheat entering any machine applying friction, where the risk of damage or fire is greatest.

From the magnetic separator, the wheat enters a disc separator, which consists of discs revolving on a horizontal axis. The surface of the discs is indented to catch individual grains of wheat but rejects larger or smaller material. The blades also act to push the wheat from one end of the machine to the other. The revolving discs discharge the wheat into a hopper, or into the continuing stream. The wheat is then directed to a stoner for removal of stones, sand, flints, and balls of caked earth or mud, which may be so close in size to the wheat grains that they cannot be adequately sifted out. Both wet and dry stoners are used for this purpose.

The wheat then moves into a scourer—a machine in which beaters attached to a central shaft throw the wheat violently against a surrounding drum—buffing each kernel and breaking off the beard. The machines also remove a large amount of dust and loose bran—skin adhering to the wheat grains. Scourers may either be horizontal or upright, with or without brushes, and adjusted for mild, medium, or hard scouring. Air currents carry off the dust and loosened particles of bran coating. Following the scouring step, the grain is typically sent through a surge bin, which acts as a storage/supply point between the cleaning house and the tempering bins or tanks.

Modern milling practices utilize conditioning or tempering before the wheat is ground. Tempering, as it is practiced in the United States, involves adding water to grain to raise the moisture of hard wheats to 15 percent to 19 percent and of soft wheats to 14.5 percent to 17 percent. After moisture is added, the wheat lies in tempering bins (with little or no temperature control) for periods of 8 to 72 hours (hr). During this time, the water enters the bran and diffuses inward causing the bran to lose its friable characteristic and to toughen. Tempering also softens or mellows the endosperm, making it easier to grind. The percentage of moisture, length of soaking time, and temperature are the three important factors in tempering, with different requirements for soft and hard wheats. Usually, tempering is done in successive steps because more than a few percent of water cannot practically be added to wheat at one time.

When the moisture is properly dispersed in the wheat for efficient milling, the grain is passed through an impact machine as a final step in cleaning, possibly after passing through an additional magnetic separation step. Discs revolving at high speed in the impact machine hurl the wheat against fingerlike pins. The impact cracks any unsound kernels, which are subsequently rejected. From the impact machines, the wheat flows to a grinding bin or hopper from which it is fed in a continuous metered stream into the mill itself.

The milling of bread wheat to flour is done with a series of roller mills, pairs of rolls which rotate in opposite directions at different rates of speed and exert relatively gentle shearing rather than crunching forces. The roller milling area is divided into two sections, the break system and the reduction system. In the break system, the kernel is broken open and the endosperm is separated from the bran and germ. The break system quite often involves four or more sets of corrugated rolls, each taking feed stock from the preceding one. After each break, the mixture of free bran, free endosperm, free germ, and bran containing adhering endosperm is sifted. The bran having endosperm still attached goes to the next break roll, and the process is repeated until as much endosperm has been separated from the bran as is possible.

The sifting system is a combination of sieving operation (plansifters) and air aspiration (purifiers). The plansifter has flat sieves piled in tiers, one above the other. The action of the sifter is rotary in a plane parallel with the floor. As the sifter moves in about a 89-mm (3.5-in) diameter circle, the small-sized particles spill through the sieve below while the oversized particles travel across the sieve to a collecting trough and are removed. As many as 12 sieves can be stacked one on top of the other, and there are four separate compartments in one plansifter. The flour and endosperm chunks (middlings) from the plansifter still contain minute bran particles, which are removed by sending the product through a purifier where air currents carry the bran away. A purifier is essentially a long oscillating sieve, inclined downwards becoming coarser from head to tail. The currents pass upward through the sieve causing the flour to stratify into endosperm chunks of different size. Aspirated materials are used for millfeed, which consists of brans and shorts.

The reduction system comprises two parts, roll mills and sifting machines. In roll mills, surfaces of the rolls are smooth, rather than grooved, and are set to reduce endosperm middling to flour-size particles and facilitate the removal of the last remaining particles of bran and germ. Plansifters are also used behind the reduction rolls, and their purpose is to divide the stock into coarse middlings, fine middlings, and flour. The coarse middlings are returned to the coarse (or sizing) rolls, and the fine middlings are returned to the fine roll, while the flour is removed from the milling system. Purifiers are often used behind the coarse reduction rolls for size grading rather than purification. Purifiers are sometimes superior to plansifters for these separation requirements.

Flour stock is transported from machine to machine by gravity or air conveying. Older mills depend upon gravity, with the wheat and flour being moved to the top of the mill by bucket elevators from which the flour flows by spouts to the rolls and to the sifters. Bucket elevators have two serious disadvantages: they are dusty and they can harbor insects. Consequently, newer flour mills have converted to the air conveying of flour and are abandoning bucket elevators and gravity spouts.

Transfer of the finished product to storage, bagging, or bulk loading is generally done by pneumatic conveying systems. Bulk storage capacity varies widely, but most mills have bulk flour storage from 2 to 4 days of production. Special railroad cars and trucks are generally used to transport bulk flour.

2.2.2.1.2 Durum wheat milling. Durum wheat has harder kernels than bread wheat and is used primarily to make pasta. In the milling of durum, middlings rather than flour are the desired product. Consequently, the break system, in which middlings are formed, is emphasized, and the part of the reduction system in which flour is formed is de-emphasized. Generally, durum processing comprises the same 5 steps as those used for flour milling. Steps 1, 2, and 5 are essentially identical for durum and flour milling. The tempering in Step 3 varies only slightly between the two processes. Only Step 4 differs significantly from the comparable flour milling step, and it will be the main focus of the discussion below.

The tempering of durum uses the same equipment as wheat, but the holding times are shorter because of the desire for middlings without flour production. Excessive tempering times soften the endosperm resulting in undesired flour production. Short tempering times maintain the hard structure of endosperm, which enhances the production of endosperm chunks.

The break system in a durum mill generally has at least five breaks and provides for the very gradual reduction of the stock necessary for good middlings production while still avoiding large amounts of break flour.

The rolls in the reduction system are used for sizing only. None are used to produce flour. They function the same as the sizing rolls in a wheat flour mill reducing the coarse middling to a uniform particle size. In a wheat flour mill, the sizing is done to produce a uniform product for further grinding on the reduction rolls. In a durum mill, however, sizing is done to make a uniform product for sale.

The sifting system of a durum mill differs from that in a wheat flour mill by the heavy reliance on purifiers. In place of plansifters, conventional sieves are much more common and are used to make rough separations ahead of the purifiers.

2.2.2.1.3 Rye milling. Rye and wheat flour milling are quite similar processes. In both instances, the purpose is to make flour that is substantially free of bran and germ. The basic type of machinery and same 5-step process is employed. The following paragraphs describe basic differences between the rye and wheat flour milling processes.

The flow through the cleaning and tempering portions of a rye mill is essentially the same as the flow used in a wheat flour mill. However, because rye is more difficult to clean than wheat, this cleaning operation must be more carefully controlled. Rye is graded for size as well as other properties, and because of the size differences, gravity tables may be used in the cleaning house to separate sizes according to weight differences. Pocket sizes in the disc machinery are also slightly different because the average rye kernel is thinner and slightly longer than the average wheat kernel.

After the rye mix has been cleaned, tempering water is added, and the rye is allowed to rest in the temper bins the desired length of time prior to milling. In contrast to wheat milling, which is a process of gradual reduction with purification and classification, rye milling does not employ gradual reduction. Both the break and reduction roller mills in a rye mill are corrugated. Following grinding, the screening systems employ plansifters like those used in a wheat flour mill. There is little evidence of purifier use in rye mills, although they are commonly used in wheat flour mills.

The wheat and rye flour milling processes are very similar because flour is the intended product of the break rolling system. In durum wheat flour milling, the intent is to produce as much middlings and as little flour as possible on the break rolls. As in wheat flour milling, the intent in rye milling is to make as much rye flour and as little middlings as possible on the break rolls. Both the greater pressure on the rolls and the corrugated surface contribute to greater flour production. As a consequence, there are more break rolls in proportion to reduction rolls in a rye mill than in a durum wheat flour mill.

2.2.2.2 Oat Milling[8,23] Oats are used predominantly for livestock feed, with a relatively small part used for human consumption in breakfast and hot cereals and baked products. The predominant use of the oats used for human consumption is for hot cereals, which accounts for about 10 percent of the total grain harvested each year. Oats are milled into two primary hot cereal products: regular oats and quick oats. The longer oats are separated from shorter oats in the process and are used to produce regular oats. The shorter oats are further reduced in size in a cutting plant and are used to produce quick oats. In addition, processed oats have been used increasingly in cold breakfast cereals, and oat flours are used in baby foods and bakery products.

The milling process for oats consists of the following seven steps as illustrated in Figure 2-5.

1. Reception, preliminary cleaning, and storage.
2. Cleaning.
3. Drying and cooling.
4. Grading and hulling.
5. Cutting.
6. Steaming.
7. Flaking.

The receiving and storage operations are comparable to those described for grain elevators and for the wheat flour milling process. They are not discussed further. The remaining operations are described below.

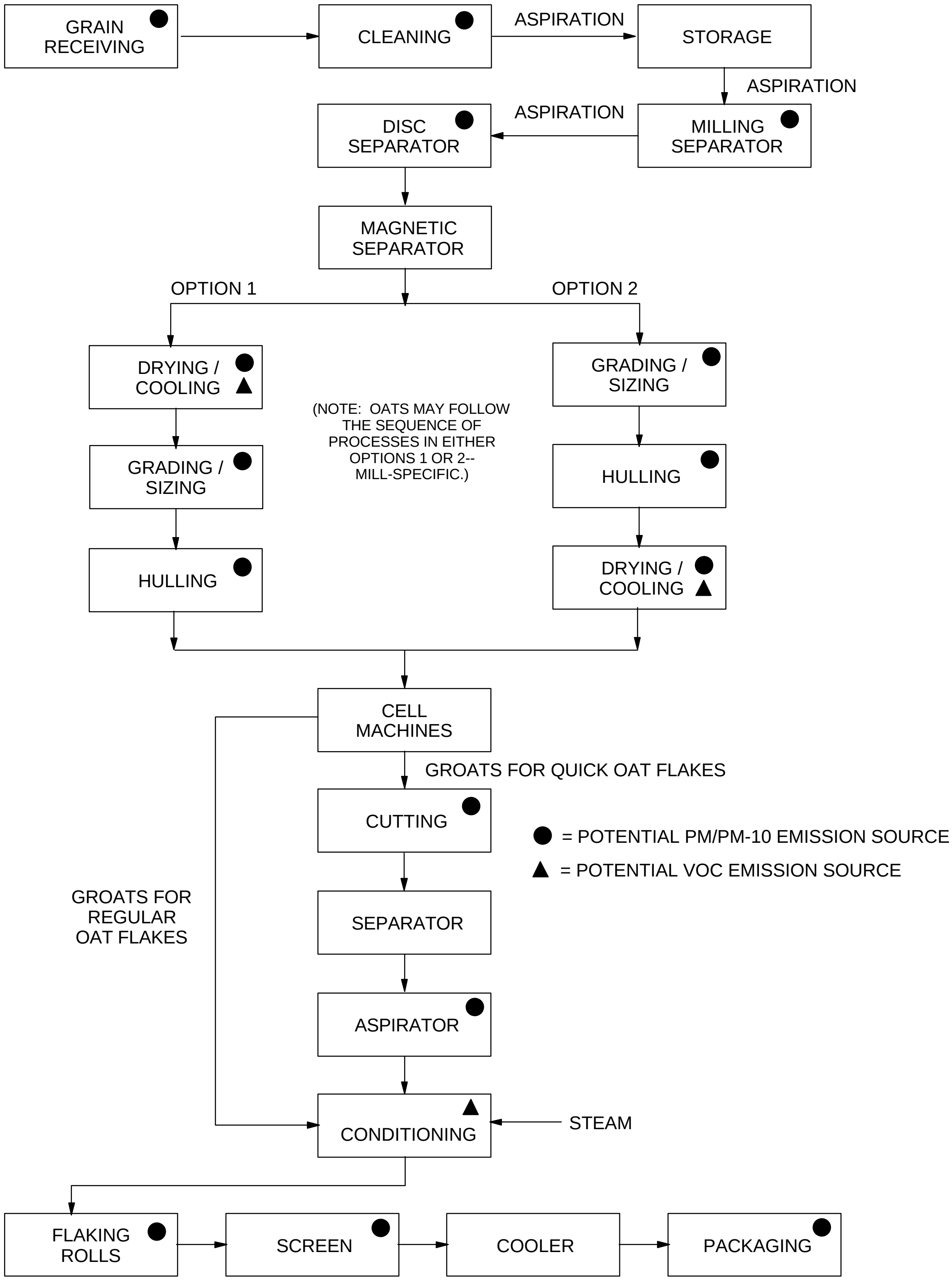

Figure 2-5. Flow diagram for oat processing operations.

Initial cleaning removes coarse field trash and objects that could damage conveying equipment and removes dust, loose chaff, and other light impurities before storage. A receiving separator incorporating one of two methods is used for this initial cleaning step to remove the coarse and light impurities. The first method uses slightly inclined wire mesh or perforated sheet metal screens that are given a reciprocating or rotary motion. The perforation openings are selected to let the oats fall through while the coarse impurities are overtailed. The second method uses horizontal, slowly rotating, coarse wire-mesh reels or cylinders. The oats are either fed into the inside of the reel, where the oats fall through while the coarse objects are overtailed, or the oats are fed onto the outside of the rotating reel and pass through while the coarse objects are carried over and evacuated from the machine. Most receiving separators, regardless of model type, incorporate an aspiration channel to remove light impurities from the oats before they leave the machine. Intake rates of the field oats arriving at the plant vary widely depending on the size and production output level of the plant; these can range from a low of 35 m^3/hr (1,000 bu/hr) at small mills to over 350 m^3/hr (10,000 bu/hr) at large facilities. After preliminary cleaning, the oats are stored until needed for processing.

After the oats are removed from storage, they are processed through a more rigorous oat cleaning system. The foreign materials removed during cleaning are corn, seeds, sticks, soybeans, barley, wheat, loose hulls, stones, and dust. The contaminants usually become mixed with the oats in the field and during handling in various grain elevators. Oats that are not suitable for milling and that are removed include the following:

1. Double oats (bosom). The hull of the primary kernel envelops the second grain. Normally, groats in both kernels are poorly developed, resulting in a high percentage of hull.
2. Pin oats. These are usually very thin and short and very poor yielding, with little or no groat inside.
3. Light oats. Although generally equal in size to normal oats, light oats contain small groats in comparison to the hull; they are separated by aspiration.
4. Other types of oats. These consist of twins and discolored, green, and hulless kernels, which may or may not be removed in the cleaning plant depending on their size.[8]

The first machine in the cleaning flow is a milling separator combining coarse and fine screening with an efficient aspiration. Different sieve deck motions are available depending on the manufacturer and design concept including rotary motion, oscillating or reciprocating motion, and combined head-end rotary motion and tail-end reciprocating motion. In a milling separator, the top sieve deck is clothed with screen material (either perforated sheet metal or wire mesh) to provide a close scalping separation. The oats and fine material fall through the top sieve layer onto the lower sieve layer (or layers) clothed with finer screens for fines removal. Most milling separators incorporate an aspiration to remove dust and light material from the oats before leaving the machine. Depending on type of separator used, the aspiration is on the oat stream entering the machine or else on the oat stream leaving the machine after screening.

The next stage of the cleaning process utilizes a series of specialized cleaning machines that selectively remove weed seeds, double oats, any remaining stones or sticks, and low-quality oats such as pin oats. These machines, which include disk separators, indented cylinders, width sizers, gravity separators, and paddy separators are described in detail in Reference 8. In this sequence of specialized cleaning operations, the oats are first routed to a disk separator for stick removal. Next the oats are classified into three size categories--stub (short) oats, medium-sized oats, and large oats--each of which has particular sizes and types of impurities. Disk separators are used to separate the oats into size categories, and each category is subjected to a variety of processes (mechanical and gravitational separation, aspiration, and magnetic separation) to remove impurities. The oats are now ready for hulling, but first they must be dried.

The next step in the oat processing system is, therefore, drying and cooling. The objectives of this stage are to efficiently inactivate the lipase or fat-splitting enzymes to prevent the development of undesirable flavors during processing and to prevent rancidity in the end product; to develop a slightly roasted flavor, which is considered desirable by most processors; and to make the oat hulls more friable, or brittle, to facilitate their removal during the subsequent dehulling stage.

Historically, most oats were dried using pan dryers, which are normally 3 to 3.7 m (10 to 12 ft) in diameter and are placed one above the other in stacks of 7 to 14. Each pan is steam jacketed and open on the top. The oats take at least 1 hr to gradually pass down through the stack and are moved in each pan from inside to outside by slowly moving sweeps. The oats then drop from the outside to the inside of the pan below. Another form of oat dryer is the radiator column type, in which a vertical column has banks of horizontal radiators arranged down the height of the column in a staggered fashion so that all of the oats come into contact with the steam-heated surfaces in their slow passages down and through the radiators. During the drying process, oats typically reach a temperature of 88° to 98°C (190° to 200°F) and the moisture content is reduced from 12 percent to 7 to 10 percent. Smaller mills use a rotary steam tube dryer, but the flavor development is generally considered to be lower than in the pan dryers. Some mills are now hulling oats with no drying or conditioning, then drying the groats separately to develop the desired toasted flavor.

After drying and cooling, the oats are ready for hulling, which separates the hull from the grain. After hulls have been removed, the oats are called groats. Hulling efficiency can be improved by prior grading or sizing of the oats. The impact huller, which is in almost universal use today, produces a better yield and requires much less horsepower than the old stone huller. The oats enter the center of a high-speed rotor with fins, which throw the oats against a rubber liner fixed to the housing of the machine. This liner, which reduces the breakage during impact, also assists in efficient separation of the hull from the groat. The huller produces a mixture of free groats, free hulls, groat chips, fines, unhulled oats, and the small amount of hulled barley that is not removed in the precleaning steps described earlier.

Again, large and short hulled oats are processed separately until the last stages of milling, which includes removal of the hulls and the final grading steps to extract unhulled kernels, wheat, and barley. The free hulls are "light" enough that aspirators remove them quite effectively. Small groats and chips, however, can be lost with the hulls so the air used in the aspirators must be carefully adjusted, particularly in the short oat system.

Grain sizing prior to hulling also assists the oat and groat separation after hulling. The groats are sufficiently shorter than oats so that a practical separation can be made by length using disc machines. However, this separation is made less effective by some oats whose groats are as long as the oat and by the huller damaging the tips of many oats that are not hulled on the first pass. The oat stream separated in this step for return hulling typically contains some groats.

Generally, the final step in the large oat system is the separation of groats totally free of whole oats that have not had the hulls removed. These groats, used the regular oat flakes, are separated by cell machines and will bypass the cutting operation. The cell machine consists of rectangular plates with indents similar to a disc machine moving up a 30-degree incline. The groats drop onto the moving plates near the center of the machine. The clean groats are carried over the top and directed to storage prior to flaking. The rejects of the cell machine, which will contain a few unhulled oats, are sent to the cutting plant for processing into quick cooking oat flakes (1 min). Cell machines for groat finishing are gradually being replaced by the more efficient gravity tables.

Those groats that are to be used in the cutting plant for quick cooking oat flakes are usually not processed to separate them completely free of whole oats and oat hulls. The cutting plant is designed to remove these contaminants. The purpose of cutting is to convert the groats into uniform pieces, two to four per groat, with a minimum of fine granules or flour. Cutting is accomplished with rotary granulators. These consist of rotating perforated drums, through which the groats align themselves endwise and fall against stationary knives that are arranged around the bottom and outside surface of the drum. The cutting fines (oat middlings) are then removed by a shaker equipped with a 22-mesh (800 µm) thin mill screen, though various meshes are used in different plants. The cutting flour is generally used as a high quality animal feed. The cut groats are separated from the uncut groats, oats, and long hulls by a cylinder separator or disc machine. The pickups of the disc are aspirated by a closed circuit or multilouver type machine that removes loose hulls or slivers that may be present in the cut groats.

The cut material is now ready for the flaking plant. Conditioning the groats for flaking is accomplished by live steaming at atmospheric pressure just prior to flaking. The steaming softens the groats and permits flaking with a minimum of breakage. Also, enzyme systems, which could cause rancidity and undesirable flavors in oatmeal, are inactivated. The steamed groats pass directly into the flaking rolls from the steamer. The cut groats are rolled into relatively thick flakes for quick cooking oatmeal. The uncut groats are flaked about 50 percent thicker. The rolls are adjusted to produce flakes of uniform quality, which are determined by a thickness or density measurement. The shakers under the rolls remove fines produced in the flaking process. Also, overcooked pieces, which are generally agglomerates of several flakes, are scalped off. The flakes also generally pass through a multilouver or terminal velocity-type cooler. Hull slivers are removed with the cooling air. The moisture content and temperature are quickly reduced to ensure acceptable shelf life.

The cooled flakes are then conveyed to the packaging system. Because quick flakes are easily broken, the flaking system is often located above and near the packaging equipment. Conveying equipment, which causes a minimum of abrasion, is used. Because of a wide density variation in the flakes, packaging must include weighing the contents of each container. The poor flowing characteristics make the package filling somewhat difficult. Generally a plunger is used to gently compress the flakes into each package.

2.2.2.3 Rice Milling[23,26-28] Nearly all rice consumed as food undergoes some type of milling operation during its preparation. Rice milling differs considerably from the milling of all other grains because the preferred form of rice is the whole grain rather than a flour or meal. However, broken kernels and small pieces are sold for manufacturing purposes, as for brewing and the manufacture of breakfast cereals or snacks. Figure 2-6 shows the distribution of the different products and by-products produced from typical rice milling operations. Brown rice is the product that remains after the hull or husk are removed, while white rice is what remains after the bran and some of the germ are removed. White rice includes both whole rice (called head rice) and broken kernels.[27]

The wet basis moisture content (MCwb) of harvested rice is 24 to 25 percent. In order to be stored safely, the rice moisture must be reduced to 13 to 14 percent MCwb. Consequently, the first step in rice processing operations after harvest is rice drying. Essentially all of the rice is dried either on the farm or at commercial drying facilities/warehouses prior to shipping to the rice mill.[12] The two types of mechanical dryers used are fixed-bed dryers and continuous-flow dryers.[27]

Fixed-bed dryers, with circular and rectangular, are used for complete on-farm drying of rice and for finish-drying after primary drying in continuous-flow dryers at commercial drying facilities. Fixed-bed dryers, which include large capacity integral bins, can also be used for temporary rice storage subsequent to drying. Circular, fixed-bed dryers are equipped with perforated floors. A fan at the base of the facility creates a high pressure area under the grain by pulling drying air from the outside, the air is forced up through the grain, and moist air is exhausted from the top of the bin. Circular-bin dryers are usually equipped with supplemental heaters used if the relative humidity of the ambient air is too high to provide adequate drying. Rectangular-bin dryers are typically used for finish drying and storage and are usually not designed with supplemental heating equipment. Large fans placed outside the bins distribute drying air through large tunnels on the floor of the bin. Air is exhausted from the vents along the top of the bin.

Most of the rice produced in the United States is dried commercially in continuous-flow dryers, which use forced heated air as the drying medium. Two common continuous-flow dryers are the mixing and nonmixing types. In a nonmixing columnar-type dryer, the rice flows by gravity in a straight path between two screens. This dryer is sometimes called a "cross-flow" dryer because air is forced to flow

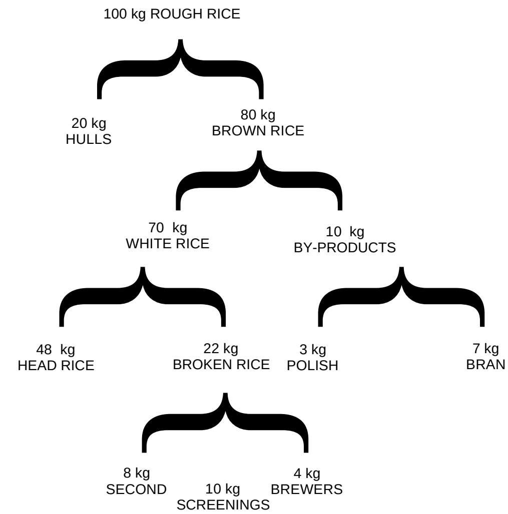

Figure 2-6. Distribution of rice products and by-products.

across a moving bed of rice. The nonmixing column-type dryer is probably the most common commercial rice dryer in use today.

One type of mixing-type columnar dryer can use baffles to promote mixing. In another type, rice flows downward over inverted V-shaped air channels. Air flows in and out alternate rows of channels, and mixing is accomplished because the inlet and outlet air ducts are offset from one another. In terms of grain quality, the mixing-type dryers promote more uniform drying of rice.

Continuous-flow rice dryers are usually operated on a multipass basis. The moisture content of rice may be reduced 2 to 4 percent (dry basis) each time it passes through the dryer. Between passes, rice is held for a short period to allow the kernel moisture gradients developed during drying time to be reduced. This holding period, which may be as long as 24 hr, is referred to as tempering. In multipass drying, the number of dryer passes and the quantity of moisture to be removed during each pass is usually determined by the individual dryer operator. Many factors, such as dryer capacity, quantity of rice to be dried, and moisture to be removed, are considered in making this decision.

After the rice is dried, it is stored and subsequently shipped to rice mills for further processing. Both conventional and parboil rice mills are used in the United States, with the former accounting for about 85 percent of the national rice crop. (Parboiled rice is obtained by partially boiling the rice using pressurized steam before it is milled.) There are three distinct stages in each of these mills: (1) rough rice receiving, cleaning, drying, and storage; (2) milling; and (3) milled rice and byproduct bagging, packaging and shipping. Figure 2-7 shows the process flow for conventional and prreboil rice mills.

Grain is received primarily by truck and rail at rice mills. Rough rice is delivered to the mill containing various kinds of foreign material, such as straw, loose hulls, bran, weed seeds, pebbles, and granules of dirt. Before cleaning, this rough rice is weighed in an automatic hopper scale to determine the weight of the uncleaned grain. The rough rice is then cleaned using combinations of scalpers, screens, and aspiration.

The precleaner system has aspiration for light impurities, an oscillating double sieve for heavy impurities, and a magnet to trap any iron particles. Light small impurities, mainly dust, are blown inside a cyclone for separation and discharge. All other impurities are discharged into sacks or containers. Because this type of precleaning machine cannot generally separate the small stones of about the same size

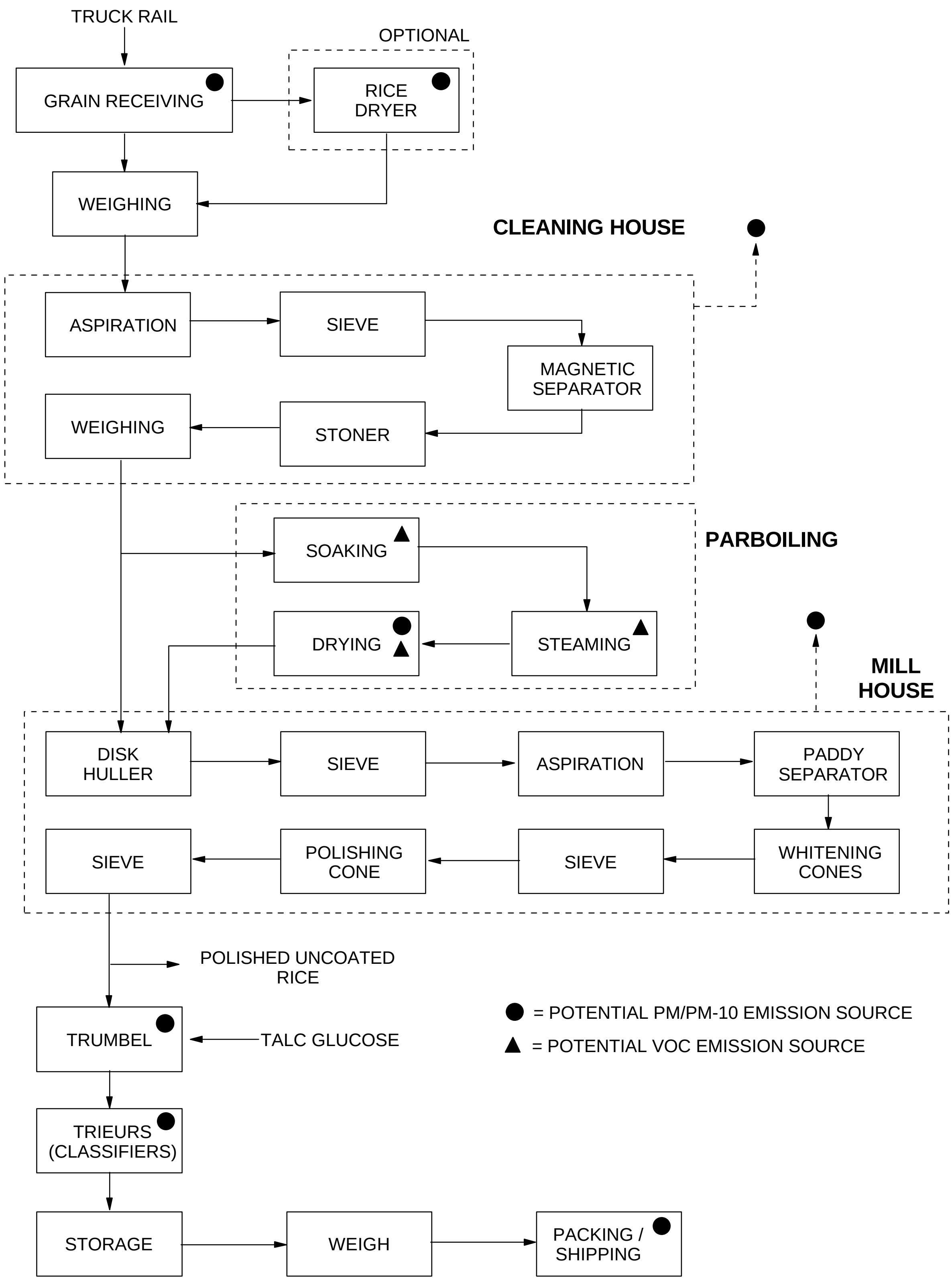

Figure 2-7. Flow diagram for conventional and parboil rice mills.

as the rice grains, the rice grain passes a stoner or gravity separator that separates the stones from the grain by using the differences in density of stones and rough rice. The grain then passes a second automatic hopper scale that weighs clean rough rice that will actually be processed in the rice mill to determine the degree of purity of the rough rice.

The milling of rough rice to produce white rice is the major milling operation conducted at U.S. rice mills. Cleaned rice is first transported to a disk huller where the rice is dehulled. Stone and rubber shellers are used for this operation. The hulls that are produced are relatively light and are readily removed from the shelled grains when the mixture is aspirated. Before the material is aspirated, it first passes through a double sieve which separates the coarse bran and small brokens (brown rice) that have been generated in the disk huller. The hulls are collected by passing the aspiration air through a product recovery device, usually a cyclone.

The product stream in the shelling process contains a mixture of unshelled rice grains and brown rice, which must be separated. This operation is performed in a device known as a paddy separator, which consists of flat cars divided into three tiers of irregular compartments. The cars are tilted in such a way that when they are rapidly shuttled, the lighter, bulkier, rough rice (commonly called paddy) is concentrated at the raised side, while the heavier brown rice migrates to the lower opposite side. The process is continuous, and streams of brown and rough rice are removed simultaneously. The unshelled paddy is then fed into another pair of shellers set closer together than the first set, and the above process of shelling, aspiration, and separation is repeated.

From the paddy machines, the brown rice is conveyed to a sequence of milling machines called whitening cones, which scour off the outer bran coats and germ from the rice kernels. Milling may be accomplished in one, two, or three distinct operations, that is, by a single pass through a mill or by consecutive passages through multiple whitening cones, depending on plant practice. The discharge from each stage contains a mixture of whole kernels and rice fragments, which are separated by sieves.

After the rice is milled, it consists of almost-white whole kernels mixed with broken kernels of different sizes. It is now ready for the brush (or polishing cone), a device for removing the white inner bran layers and the proteinaceous aleurone layer. The brush is essentially a large, vertical, stationary, cylindrical screen inside of which rotates a drum with overlapping leather flaps. The rice enters at the top of the machine and, as it progresses toward the bottom, is rubbed against the screen by the leather flaps. The white flour mixture of fine bran and aleurone layer removed by abrasive action is forced through the screen and is collected and sacked. The collected "polishings" are usually sold as a byproduct for animal feed. The whitening cones, all coated with an abrasive material, and the polishing cone, covered with leather strips, are connected to an aspiration system for grain cooling. At the same time, this aspiration system removes some bran, which is recovered through one or more cyclones.

At this stage, the rice kernel consists of the white, starchy endosperm, together with fragments of the aleurone layer. Rice may be sold in this form as polished, uncoated rice or it may be conveyed to machines known as trumbels, in which it is coated with talc and glucose. This inert, harmless coating is used to give the rice a gloss.

Even with care, some of the kernels are broken during milling. A series of classifiers known as trieurs separate the different size kernels. The whole and three-quarter kernels are screened into a fraction and designated as "head" rice, the one-third to three-quarter rice grains are known as "screenings," and the still smaller fragments are termed "brewers" since they form a useful brewing adjunct.

Following the trieurs, the rice is transferred to bulk storage prior to packing and shipping. For packing, the rice is transported to a packing machine where the product is weighed and placed in 45.4 kg (100 lb) burlap sacks. While burlap sacks are the primary packaging material, some mills may ship the finished rice in bulk or packaged in paper bags or cardboard boxes.[26,28]

Some mills in the United States produce only parboiled rice, while others produce both white and parboiled rice. All parboiling mills are similar in that they all involve soaking rough rice following cleaning, then steaming, drying, and milling. Pressure vessels are utilized for the steaming step and steam tube dryers are employed to dry the rice to 11 percent to 13 percent moisture. Following the drying step, the rice is milled in conventional equipment to remove hull, bran, and germ. The better head yields obtained in the milling of parboiled rice than in the milling of raw rice defrays to a considerable degree the cost of parboiling so that parboiled rice sells for a little more than white rice.

2.2.2.4 Corn Dry Milling[23,29,30] Corn is dry milled by two different systems--degerming and nondegerming. The nondegerming system grinds corn (preferably a white dent variety), into a meal with little, if any, removal of germ. Near the turn of the 20th century, the Beall corn degerminator was introduced to the corn dry milling industry. The development of degerming equipment resulted in a milling system that removes practically all the hull, germ, and tip cap from the kernel to produce corn grits, meal, flour, hominy feed, and oil. Because it is the principal system used in the United States, the degerming system will be the focus of the corn dry milling process description below. Figure 2-8 shows a flow diagram for the degerming corn dry milling process, which is more accurately called the tempering degerminating (TD) system.

The degerming system involves the following steps after receipt of the grain.

1. Dry cleaning, and if necessary, wet cleaning of the corn.
2. Tempering of the corn (by controlled addition of moisture).
3. Separation of hull, germ, and tip cap from the endosperm in the degerminator.
4. Drying and cooling of degermer product.
5. Multistep milling of degermer product through a series of roller mills, sifters, aspirators, and purifiers.
6. Further drying of products, if necessary.
7. Processing of germ fraction for recovery of crude corn oil.
8. Packaging and shipping of products.

The individual steps in the milling process are discussed in the following paragraphs. Unloading and dry cleaning of corn involves essentially the same processes as previously described for wheat processing. However, for corn cleaning, surface dirt and spores of microorganisms can best be removed by wet cleaning rather than dry. Conventional wet cleaning equipment consists of a washing-destoning unit followed by a mechanical-tube dewatering unit.

After cleaning, the corn is sent through the tempering or conditioning step. Normally, the moisture content of the corn is raised to about 21 percent to 25 percent rather than the 17 percent used for wheat milling because the germ of the corn tends to be more friable than the wheat germ. If it is too dry, it will break into small flour sized pieces during degerming. If enough water is added, not only is the bran toughened, but so is the germ.

Degerming follows the conditioning or tempering step. The Beall degermer is used in most degerming mills in the United States. The Beall degermer is essentially an attrition device built in the form of a cone mill. It consists of a cast-iron, cone-shaped rotor mounted on a rotating, horizontal shaft in a conical cage. Part of the cage is fitted with perforated screens and the remainder with plates having conical protrusions on their inner surface. The cone has similar protrusions over most of its surface. Also, the small or feed end of the cone has spiral corrugations to move the corn forward. Attached to the large end of the cone is a short cylinder corrugated in an opposing direction to retard the flow. The product leaves in two streams. Thru-stock, normally about 60 percent to 75 percent of the degermer stock, is discharged through the perforated screens and contains a major portion of the released germ, hull, and degermer fines, as well as some of the grits. Tail stock (typically called tail hominy), in which large grits predominate, escapes through an opening in an end plate facing the large end of the cone. This tail hominy fraction is

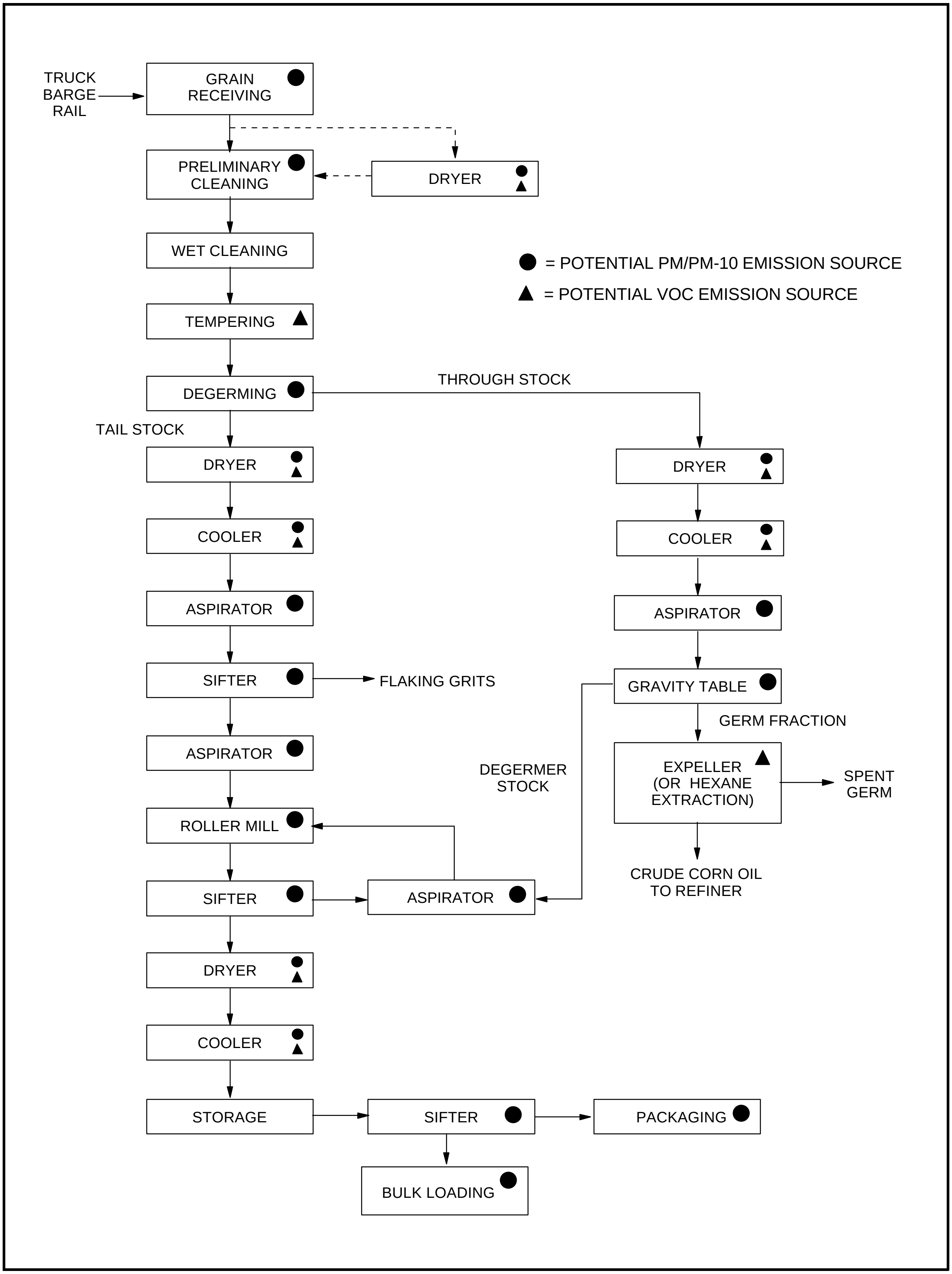

Figure 2-8. Simplified process flow diagram for a corn dry milling operation with degerming.

dried, cooled, and sifted, and part of it is isolated as large flaking grits. The remainder is sent to the roller mills for reduction into smaller fractions, such as coarse, medium, or fine grits; mills; or flours.

The bran and germ fractions (together) pass through a screen on the underside of the degerminator and become the "thru stock" stream. This stream is dried, cooled, aspirated to remove the bran, and processed on gravity tables to separate germ and endosperm.

The moisture content of all degermer product streams must be in the 15 percent to 18 percent range for proper milling. Rotary steam-tube (i.e., indirect-fired) dryers with air drawn through the dryer to carry off the vaporized moisture are often used to dry the degermer products. Coolers may be counterflow or crossflow rotary, vertical gravity, louver, or fluid bed. In rotary coolers, lifting flights rotating inside a horizontal shell shower material through an airstream and move the stock towards the outlet. In the vertical cooler, solids flow by gravity down through a column containing louvers for alternately introducing and withdrawing cooling air. Air is drawn through the cooler either by a fan or a natural draft tower. Temperature of the stock is lowered to 32° to 37°C (90° to 100°F) in the cooler and the cooling step removes about 0.5 percent moisture.

After drying and cooling, the tail hominy fraction moves to the primary milling section of the dry corn mill. The milling section in a dry corn mill consists of sifting, classifying, milling, purifying, aspirating, and possibly final drying operations. After drying and cooling, the degermer stock is sifted or classified by particle size and enters into the conventional milling system. The feed to each pair of rolls consists of selected mill streams produced during the steps of sifting, aspirating, roller milling, and gravity table separating in preceding stages of the process. For the production of specific products, various streams are withdrawn at appropriate points in the milling process. A number of process streams often are blended to produce a specific product. The finished products are stored temporarily in working bins, dried and cooled if necessary, and rebolted (i.e., sifted) before packaging or shipping in bulk.

The germ fraction of the thru stock can be expelled or hexane-extracted to remove the oil, and the spent germ or germ cake becomes one of the by-product streams. (Some of the corn dry millers do not further process the germ but sell it to other companies that do). The fines separated from the thru stock endosperm are usually high in oil, fine fiber, and tip caps; they become one of the by-product streams known as "standard meal." The bran, germ cake, standard meal, and broken corn (isolated from whole corn before entering the corn mill) are combined, dried, and ground up together to become the main by-product of the corn dry millers, which is known as "hominy feed." Since none of the dry millers refine corn oil, the crude oil obtained from either expelling or extraction is sold to one of several oil refiners in the United States. The main portion of the endosperm isolated from the thru stock is processed in the same way as the tail hominy fraction to produce prime grits, meals, and flours. A more detailed discussion of the corn oil extraction process is included in Section 9.11.1, Vegetable Oil Processing.

2.2.2.5 Animal Feed Mills[18,19,22,24,30] Processing of grains and other ingredients into mixed feed consists of converting the grains and other constituents into the form and size desired in the finished feed, adding other ingredients and mixing them with the grains, then forming a finished feed in the desired shape and consistency. The basic forms of finished feed are mash, pellets, and crumbles. The latter are pellets that have been formed and then crushed or broken. The processes described in the following paragraphs are typical of most feed mill facilities. It is not to be inferred that all of these operations are conducted at every feed mill, nor is it to be inferred that other operations may not also be used.

Feed mills use two operations in the production of mash and four or more in the manufacture of pellets. Grinding and mixing are the two basic operations in feed milling. Pelleting and pellet cooling are additional operations in the manufacture of pellets. If pellets are broken into "crumbles" or "granules," screening follows the crumbling operation.

As shown in Figure 2-9, the manufacture of feed begins with receiving of ingredients at the mill. Over 200 ingredients may be used in feed manufacture, including grain, by-products (e.g., meat meal, bone

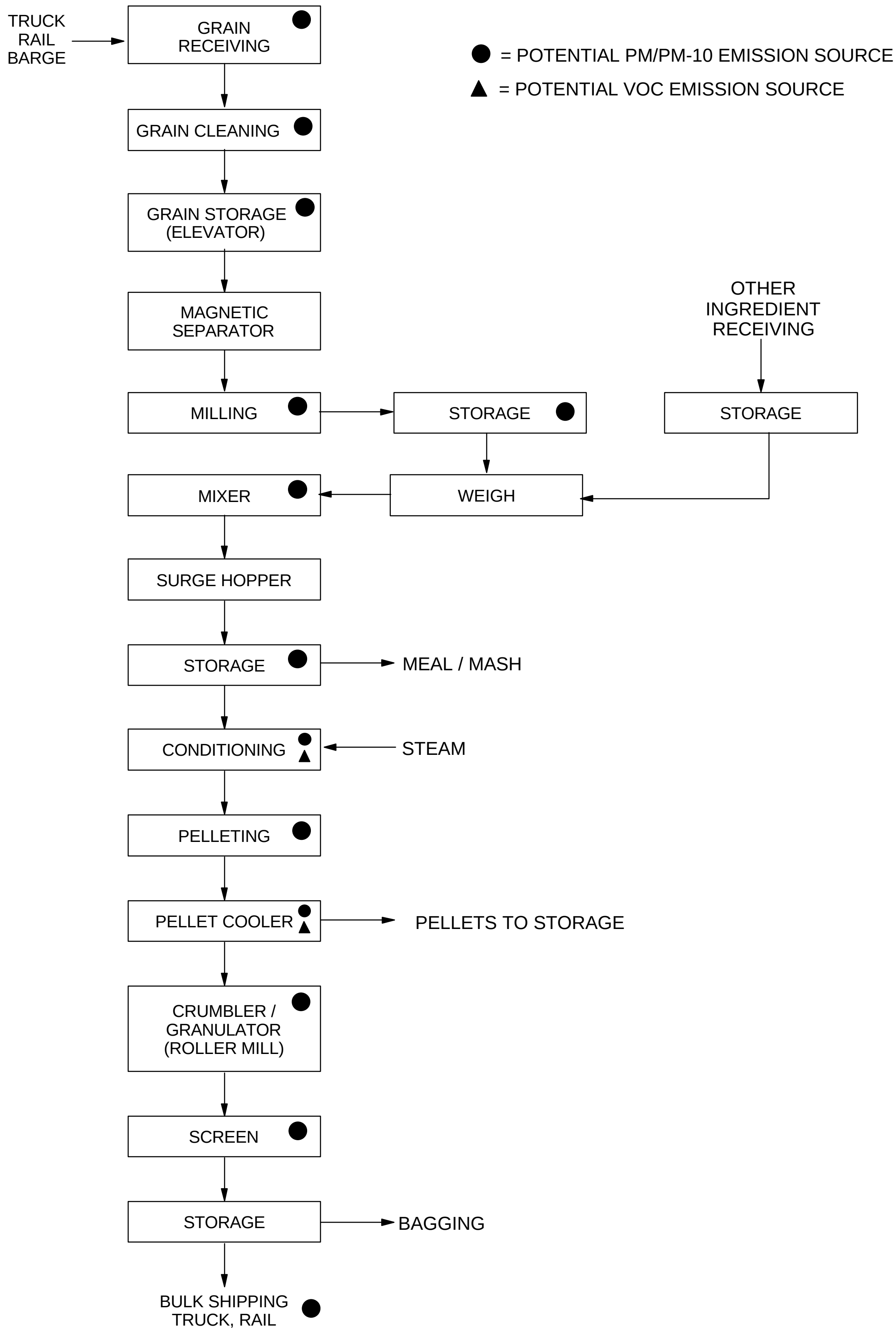

Figure 2-9. Typical animal feed milling process flow diagram.

meal, beet and tomato pulp), minerals which are used in very small portions, medicinals, and vitamins. Grain is usually received at the mill by hopper bottom truck and/or rail cars, or in some cases, by barge. Materials received in bulk, such as whole grains and soybean meal, are unloaded and handled in much the same way as grain elevators, but on a smaller scale. Because the grain receiving pits and legs at feed mills have smaller capacities than those at grain elevators, it is likely that receiving pits at feed mills achieve choke flow during unloading quicker, and more often, than at grain elevators. For this reason, the dust emission rate for grain receiving operations at a feed mill will likely be lower than those at grain elevators.

The actual movement of ingredients within the mill usually is done by gravity. First, however, the grain must be lifted via bucket elevators above the highest processing machine before the gravity process can begin. For horizontal movement or slight elevation, a screw-type conveyor (made of mild or stainless steel), a drag conveyor (in which single or double chains haul grain along a stainless steel chute), a continuous belt (with a V-trough in its center), or an air system (in which grain is carried along in a jet-like stream of compressed air) may be used. In modern feed mills, this transport equipment is connected with closed spouting and turnheads, covered drag and screw conveyors, and tightly sealed transitions between adjoining equipment to reduce internal dust loss and consequent housekeeping costs. Also many older facilities have upgraded to these closed systems.

Most mills direct feed ingredients, especially grains, through cleaning equipment prior to storage. Cleaning equipment includes scalpers to remove coarse materials from the feed ingredients before they reach the mixer. Separators, which perform a similar function, often consist of reciprocating sieves that separate grains of different sizes and textures. Some mills employ these units to rough grade grain as to quality and weight.

Magnets are installed ahead of the grinders and at other critical locations in the mill system to remove tramp iron, bits of wire, and other foreign metallic matter, which could harm machinery and contaminate the finished feed. Both permanent and electric magnets are used. Chute and rotary magnets are also commonly used. From the cleaning operation, the ingredients are directed to storage. Bulk ingredients are stored in concrete silos, steel tanks, or wooden bins. Wooden bins are generally found only in older feed mills.

After grain is removed from storage, it is transferred to the grinding area where whole grains, primarily corn, are ground prior to mixing with other feed components. The hammermill is the most widely used grinding device. The grinding chamber consists of rows of loosely mounted "swing" hammers or plates of hardened metal. These hammers pulverize the grain by striking it as they swing. The pulverized material is forced out of the mill chamber when it is ground finely enough to pass through the perforations in the mill screen. Several sizes of screen openings are used, depending on the fineness of the desired end product.

Mixing is the most important process in feed milling and is normally a batch process. Ingredients are weighed before mixing. Micro-ingredients, such as trace minerals and drugs, are weighed on bench or floor scales. Whole or ground grain and other materials added in comparatively large amounts, such as wheat middlings and soybean meal, are weighed in a hopper scale with capacity corresponding to the capacity of the mixer (0.91 to 2.7 Mg or 1 to 3 tons). In large mills (180 Mg/day [200 tons/day] and larger), ingredients are moved by conveyor from bins to the scale. In smaller mills [27 Mg/day (30 tons/day)] a "weigh buggy," which is a hopper and scales on wheels, is generally used. A weigh buggy has a capacity of about 450 kg (1,000 lb) and is wheeled under the bins from which ingredients are to be drawn for a given mix. After the ingredients are weighed in the buggy, it is wheeled to the mixer where it is unloaded. Liquids, such as vitamin feeding oils, fish solubles, molasses, and fat, are included in the ingredients fed to the mixer.

Mixers may be either a vertical or horizontal type. Vertical mixers utilize a screw to raise the ingredients from the bottom to the top of a mixing tank through an axial pipe from which the ingredients flow out, into, and back to the bottom of the tank. Horizontal mixers move the ingredients in a horizontal direction with right- and left-hand, narrow helical ribbons or paddles attached to a shaft. The paddle-type mixer is more suitable when the molasses content of the formula is high (30 percent to 40 percent) or for continuous instead of batch mixing.   Horizontal mixers have a higher mixing rate than vertical mixers and are used in large feed mills. Horizontal mixers are provided with a surge hopper underneath the mixing chamber so that the mixing process is not interrupted by conveying the mixed feed to storage. A mixer and its scale are sized to provide simultaneous weighing of the ingredients in the scale hopper, mixing the ingredients in the mixing chamber, and conveying the mixed feed from the surge hopper to storage. The material produced as an end product from the mixer is meal, or mash, and may be marketed in this form. If pellets are to be made, the meal is conditioned with steam prior to being made into pellets.

Pelleting is a process in which conditioned meal is forced through dies. Pellets are usually 3.2 to 19 mm (1/8 to 3/4 in.) in diameter and of similar length. After pelleting, pellets are cooled and dried in pellet coolers through which ambient air is drawn. Pellet cooler exhaust is usually passed through cyclone dust collectors. Pellet coolers are of either horizontal or vertical types. Vertical coolers are less expensive with regard to both purchase and maintenance cost. Horizontal coolers may be used where space is not available for vertical coolers, and are more satisfactory for feeds with high molasses content. Feeds with high molasses content are often dusted with bentonite or cottonseed meal to prevent caking.

If pellets are to be reduced in size, which is necessary for such use as baby-chick feed, they are passed through a crumbler, or granulator. This machine is a roller mill with corrugated rolls. Crumbling is a more economical method of producing small pellets than using dies with the requisite-size holes because the use of small dies seriously restricts production. The roller mill is usually located directly below the cooler and is provided with a bypass for use when pellets are sent to storage without crumbling. Crumbles must be screened to remove fines and oversized materials, which are recycled to the pellet process.

The product is sent to storage bins via closed elevator legs and gravity feed. Finished feed is bagged by automatic bagging machines, which are equipped with scales, or is shipped in bulk in trucks and railroad cars.

2.2.2.6 Malted Barley Production[37-39] Barley is shipped by railcar or truck to malting facilities. A screw conveyor or bucket elevator typically transports barley to storage silos or to the cleaning and sizing operations. The barley is cleaned and separated by size (using screens) and is then transferred to a malthouse where it is rinsed in steeping tanks (steeped) and is allowed to germinate. Following steeping and germination, "green" malt is dried, typically in an indirect-, natural gas-fired malt kiln. Malt kilns typically include multiple levels, called beds or layers. For a two-level kiln, green malt, with a moisture content of about 45 percent, enters the upper deck of the kiln and is dried, over a 24-hour period, to between 15 and 20 percent. The barley is then transferred to the lower deck of the kiln, where it is dried to about 4 percent over a second 24-hour period. Some facilities burn sulfur in a sulfur stove and exhaust the stove into the kiln at selected times during the kiln cycle. The sulfur dioxide serves as a fungicide, bactericide, and preservative. Malted barley is then transferred by screw conveyor to a storage elevator until it is shipped.

2.3 EMISSIONS

The main pollutant of concern in grain storage, handling, and processing facilities is particulate matter (PM). Organic emissions (e.g., hexane) from certain operations at corn oil extraction facilities may also be significant. These organic emissions (and related emissions from soybean and other oilseed processing) are discussed in AP-42 Section 9.11.1. Also, direct fired grain drying operations and product dryers in grain processing plants may emit small quantities of VOC's and other combustion products. The following sections focus primarily on PM sources at grain elevators and grain milling/processing facilities. However, potential sources of VOC are also identified even though no data are currently available to quantify the emission of these pollutants.

2.3.1 Grain Elevators[12,23,24,32,33]

Except for barge and ship unloading and loading activities, the same basic operations take place at country elevators as at terminal elevators, only on a smaller scale and with a slower rate of grain movement.

Because PM emissions at both types of elevators are similar, they will be discussed together in this subsection.

In trying to characterize emissions and evaluate control alternatives, potential PM emission sources can be classified into three groups. The first group includes external emission sources (grain receiving and grain shipping), which are characterized by direct release of PM from the operations to the atmosphere. These operations are typically conducted outside elevator enclosures or within partial enclosures, and emissions are quickly dispersed by wind currents around the elevator. The second group of sources are process emission sources that may or may not be vented to the atmosphere and include grain cleaning and headhouse and internal handling operations (e.g., garner and scale bins, elevator legs, and transfer points such as the distributor and gallery and tunnel belts). These operations are typically located inside the elevator structure. Dust may be released directly from these operations to the internal elevator environment, or aspiration systems may be used to collect dust generated from these operations to improve internal housekeeping. If aspiration systems are used, dust is typically collected in a cyclone or fabric filter before the air stream is discharged to the atmosphere. Dust emitted to the internal environment may settle on internal elevator surfaces, but some of the finer particles may be emitted to the environment through doors and windows. For operations not equipped with aspiration systems the quantity of PM emitted to the atmosphere depends on the tightness of the enclosures around the operation and internal elevator housekeeping practices. The third group of sources includes those processes that emit PM to the atmosphere in a well-defined exhaust stream (grain drying and storage bin vents). Each of these operations is discussed in the paragraphs below.

The amount of dust emitted during the various grain-handling operations may depend upon the type of grain being handled, the quality or grade of the grain, the moisture content of the grain, the speed of the belt conveyors used to transport the grain, and the extent and efficiency of dust containment systems (i.e., hoods, sheds, etc.) in use at an elevator. Part of the dust liberated during the handling of grain at elevators gets into the grain during the harvesting operation.[31] However, most of these factors have not been studied in sufficient detail to permit the delineation of their relative importance to dust generation rates.

Grain dust emitted from grain elevator handling operations comprises about 70 percent organic material, about 17 percent free silica (silicon dioxide), and specific materials in the dust, which may include particles of grain kernels, spores of smuts and molds, insect debris, pollens, and field dust. Data recently collected on worker exposure to grain dust indicate that the characteristics of the dust released from processing operations to the internal elevator environment vary widely.[33] The fraction of respirable dust (i.e., those dust particles equal to or less than 10 µm in diameter) ranged from about 1 percent to over 60 percent with an average of 20 and 26 percent for country and export elevators respectively. Those elevators handling primarily wheat had an average respirable fraction of about 30 percent while those handling primarily corn and soybeans had an average respirable fraction of slightly less than 20 percent. Because these dusts have a high organic content and a substantial suspendible fraction, concentrations above the minimum explosive concentration (MEC) pose an explosion hazard. Housekeeping practices instituted by the industry have reduced explosion hazards, and this situation is rarely encountered in work areas.

Elevators in the United States receive grain by truck, railroad hopper car, and barge. The two principal factors that contribute to dust generation during bulk unloading are wind currents and dust generated when a falling stream of grain strikes the receiving pit. Falling or moving streams of grain initiate a column of air moving in the same direction. Grain unloading is an intermittent source of dust occurring only when a truck or car is unloaded. For country elevators it is a significant source during the harvest season and declines sharply or is nonexistent during other parts of the year. At terminal elevators, however, unloading is a year-round operation.

Trucks, except for the hopper (gondola) type, are generally unloaded by the use of some type of truck dumping platform. Hopper trucks discharge through the bottom of the trailer. Elevators are often designed with the truck unloading dump located in a drive-through tunnel. These drive-through areas are sometimes equipped with a roll-down door on one end, although, more commonly they are open at both ends so that the trucks can enter and leave as rapidly as possible. The drive-through access can act as a "wind-tunnel" in that the air may blow through the unloading area at speeds greater than the wind in the open areas away from the elevator. However, the orientation of the facility to the prevailing wind direction can moderate this effect. Many facilities have installed either roll-down or bi-fold doors to eliminate this effect. The use of these doors can greatly reduce the “wind tunnel” effect and enhance the ability to contain and capture the dust.

The unloading pit at a grain elevator usually consists of a heavy grate approximately 3.05 m x 3.05 m (10 ft x 10 ft) through which the grain passes as it falls into the receiving pit. This pit will often be partially filled with grain as the truck unloads because the conveyor beneath the pit does not carry off the grain as fast as it enters. The dust-laden air emitted by the truck unloading operation results from displacement of air out of the pit plus the aspiration of air caused by the falling stream of grain. The dust itself is composed of field dirt and grain particles. Unloading grain from hopper trucks with choke flow-practices can provide a substantial reduction in dust emissions.

Similarly, a hopper railcar can be unloaded with minimal dust generation if the material is allowed to form a cone around the receiving grate (i.e., choke feed to the receiving pit). This situation will occur when either the receiving pit or the conveying system serving the pit are undersized in comparison to the rate at which material can be unloaded from the hopper car. In such cases, dust is generated primarily during the initial stage of unloading, prior to establishment of the choked-feed conditions. Dust generated by wind currents can be minimized by the use of a shed enclosed on two sides with a manual or motorized door on one end or a shroud around the hopper discharge.

In most cases, barges are unloaded by means of a retractable bucket type elevator that is lowered into the hold of the barge. There is some generation of dust in the hold as the grain is removed and also at the top of the leg where the grain is discharged onto the transfer belt. This latter source is more appropriately designated a transfer point.

The loadout of grain from elevators into railcar, truck, barge, or ship is another important source of PM emissions and is difficult to control. Gravity is usually used to load grain from bins above the loading station or from the scale in the headhouse. The main causes of dust emissions when loading bulk grain by gravity into trucks or railcars is the wind blowing through the loading sheds and dust generated when the falling stream of grain strikes the truck or railcar hopper. The grain leaving the loading spout is often traveling at relatively high velocity and librates a considerable amount of dust as the grain is deposited in the car or truck. Dust emitted during loading of barges and ships can be at least equal to, or maybe greater than, PM generated during loading of trucks or railcars. The openings for the holds in these vessels are large, making it very hard to effectively capture the emissions. The use of deadboxes, aspiration, socks, tents, or other means are often used to reduce dust emissions.

Grain dryers present a difficult problem for air pollution control because of the large volumes of air exhausted from the dryer, the large cross-sectional area of the exhaust, the low specific gravity of the emitted dust, and the high moisture content of the exhaust stream. The rate of emission of PM from grain dryers is primarily dependent upon the type of grain, the dustiness of the grain, and the dryer configuration (rack or column type). The particles emitted from the dryers, although relatively large, may be very light and difficult to collect. However, during corn drying the characteristic "bees wing" is emitted along with normal grain dust. "Bees wing," a light flaky material that breaks off from the corn kernel during drying and handling, is a troublesome PM emission. Essentially, all bees wing emissions are over 50 µm in diameter, and the mass mean diameter is probably in the region of 150 µm. In addition to the bees wings, the dust discharged from grain dryers consists of hulls, cracked grain, weed seeds, and field dust. Effluent from a corn dryer may consist of 25 percent bees wing, which has a specific gravity of about 0.70 to 1.2. Approximately 95 percent of the grain dust is larger than 50 µm.[23]

Cross-flow column dryers have a lower emission rate than rack dryers because some of the dust is trapped by the column of grain. In order to control the dust emitted from the columns, it is necessary to build an enclosure. This enclosure also serves as a relatively inefficient settling chamber. New grain dryers being sold today do not require the use of enclosures. In rack dryers, the emission rate is higher because the turning motion of the grain generates more bees wings and the design facilitates dust escape. Some rack dryers are exhausted only from one or two points and are thus better suited for control device installation. The EPA's NSPS for grain elevators established visible emission limits for grain dryers by requiring 0 percent opacity for emissions from column dryers with column plate perforations not to exceed 2.4 mm diameter (0.094 in.) or rack dryers with a screen filter not to exceed 50 mesh openings.

Equipment used to clean grain varies from simple screening devices to aspiration-type cleaners. Both types of systems potentially generate substantial quantities of PM depending on the design and extent of enclosure.

Both country and terminal elevators are usually equipped with garner and scale bins for weighing of grain. A country elevator may have only one garner bin and scale bin. However, a terminal elevator has multiple scale and garner bin systems, each with a capacity ranging from 42.3 to 88.1 m^3 (1,200 to 2,500 bu) to process 1,233 to 2,643 m^3/hr (35,000 to 75,000 bu/hr). Dust may be emitted from both the scale and garner bin whenever grain is admitted. The incoming stream of grain displaces air from the bin, and the displaced air entrains dust. The potential for emissions depends on the design of the system. For example, some facilities employ a relief duct that connects the two pieces of equipment to provide a path for displaced air. Also, in some cases, the bins are completely open at the top while some systems are completely enclosed.

The leg may be aspirated to remove dust created by the motion of the buckets and the grain flow. A variety of techniques are used to aspirate elevator legs. For example, some are aspirated at both the top and bottom; others are fitted with ducting from the top to the bottom in order to equalize the pressure, sometimes including a small blower to serve this purpose. The collected dust is discharged to a cyclone or filter. Leg vents may emit small amounts of dust under some operating conditions. However, these vents are often capped or sealed to prevent dust emissions. The sealing or capping of the vent is designed to act as an explosion relief vent after a certain internal pressure is reached to prevent damage to the equipment.

When grain is handled, the kernels scrape and strike against each other and the conveying medium. This action tends to rub off small particles of chaff and to fragment some kernels. Dust is continuously generated, and the grain is never absolutely clean. Belt conveyors have less rubbing friction than either screw or drag conveyors, and therefore, generate less dust. Dust emissions usually occur at belt transfer points as materials fall onto or away from a belt. Belt speed has a strong effect on dust generation at transfer points. Examples of transfer points are the discharge from one belt conveyor or the discharge from a bin onto a tunnel belt.

Storage bin vents, which are small screen-covered openings located at the top of the storage bins, are used to vent air from the bins as the grain enters. The grain flow into a bin induces a flow of air with the grain, and the grain also displaces air out of the bin. The air pressure that would be created by these mechanisms is relieved through the vents. The flow of grain into the bin generates dust that may be carried out with the flow of air through the bin vents. The quantity of dust released through the vents increases as the level of the grain in the bin increases. Bin vents are common to both country and terminal elevators, although the quantity of dust emitted is a function of the grain handling rate, which is considerably higher in terminal elevators.

2.3.2 Grain Milling and Processing

2.3.2.1 Wheat Flour and Related Dry Grain Milling[23] The primary pollutants of concern for dry grain milling operations are PM and PM-10, but small quantities of VOC or combustion products may be emitted from drying operations at grain mills. The focus of this discussion will be on PM and PM-10 emissions. Because wheat flour milling is by far the most common dry milling process, its emissions and emission sources will be addressed in some detail first in the discussion below. Then, the discussion of durum, rye, and oat milling will focus on differences between emissions from those milling processes and wheat flour milling emissions.

2.3.2.1.1 Wheat flour milling. The sources of air pollution in a wheat flour mill complex can be grouped into three main categories: grain receiving and handling operations; grain cleaning (cleaning house); and milling operations. Table 2-6 presents some of the more significant potential sources of air pollution in each category.

TABLE 2-6. POTENTIAL SOURCES OF AIR EMISSIONS IN A WHEAT FLOUR MILL COMPLEX[a]

I.	Grain receiving and storage: 1. Grain receiving 2. Grain handling 3. Grain cleaner 4. Grain storage	III.	Milling: 1. Break rolls 2. Plansifters 3. Purifiers
II.	Cleaning house 1. Separator 2. Aspirator 3. Disc separator 4. Scourer	IV.	Product and byproduct and shipping: 1. Bulk loading- a. Flour b. Byproduct 2. Bagging station

[a]Reference 23.

Dust emission sources associated with grain receiving are similar to those discussed for grain elevators. Nearly all the operations associated with grain receiving and subsequent transfer to storage are potential sources of PM emissions. These grain unloading and cleaning steps are the main sources in this part of the mill complex.

Grain dust, dirt, seeds, and chaff are all emitted from the equipment used in the cleaning house. The separator, aspirator, and scouring equipment are the principal sources of emissions in the cleaning house. In the mill house, the product recovery systems associated with the various pieces of milling equipment are potential sources of emission; bran and flour would be the principal materials emitted from these sources. Flour shipping operations may not be a significant dust source because efforts are made to minimize loss of the valuable final product. Loading of byproducts may be a significant dust source depending upon the loading procedures used at specific mills.

2.3.2.1.2 Durum wheat milling. The sources of air pollution in a durum mill parallel those of a wheat flour mill and can be grouped into the same three main categories: (1) grain receiving and handling operations; (2) grain cleaning (cleaning house); and (3) milling operations. Nearly all the operations associated with grain receiving and subsequent transfer to storage are potential sources of dust. As with wheat flour milling, grain unloading and cleaning steps are the main sources of PM emissions.

2.3.2.1.3 Rye milling. As with durum milling, air pollution sources in a rye flour mill parallel those in a wheat flour mill. The only substantive difference in emission sources is in the degerming section of the mill, which has no counterpart in the wheat flour mill. Small quantities of PM emissions are generated, but because highly efficient product recovery devices are used, they are expected to be minimal.

2.3.2.2 Oat Milling[23] The operations and equipment in an oat mill that are main sources of air pollutants are shown in Table 2-7. Dust emission sources associated with grain receiving and storage are essentially the same as those in other grain elevator operations. The handling of oats is reported to be dustier than many other grains, but no data have been located that would allow a quantitative comparison.

TABLE 2-7. POTENTIAL SOURCES OF AIR EMISSIONS IN AN OAT MILL[a]

I. Receiving, storage and mixing:	V. Cutting and flaking:
1. Grain receiving	1. Cutters
2. Grain handling	2. Separators
3. Storage	3. Aspirators
	4. Steamers
II. Cleaning:	5. Groat conditioners
1. Duo aspirator	6. Flaking rolls
2. Receiving separator	7. Coolers
3. Disc separators	
	VI. Packing and shipping:
III. Drying:	1. Packing station
1. Pan dryer	2. Bulk loading
2. Cooler	
	VII. Byproduct system:
IV. Grading, hulling, and finishing:	1. Hammermills
1. Disc separators	
2. Hullers and aspirators	
3. Cell machines or gravity tables	

[a]Reference 23.

The separation requirements in an oat mill, unlike wheat milling, necessitate extensive use of aspirators, which are expected to be a major source of emissions from the oat milling process. Oat milling also includes coolers in the drying and flaking operations. Cooling is accomplished by direct contact with a stream of forced air, which could also represent a significant source of dust emissions.

The pan dryer and steamer may not be significant sources of dust emissions, but they may be potential sources of odors. As such, they may be minor sources of VOC emissions. In some oat mills, the hulls are ground in hammermills, another potentially significant source of PM emissions.

Because nearly all the grain dust and byproducts collected in an oat mill are used in animal feed and other products, control devices are generally considered as an integral part of the process equipment. Therefore, the control devices are typically referred to as the emission points.

2.3.2.3 Rice Milling[23] In rice mills, air pollutants result primarily from: (1) grain receiving, cleaning, and storage operations; and (2) rice milling equipment and byproduct processing/loading operations. Table 2-8 presents some of the more significant potential sources of air pollution in rice mills.

Emission sources associated with the grain receiving, cleaning, and storage operations are similar to those involved with all grain processing. For those mills that dry rice, the rice dryers present a very troublesome source of emissions. Combine-harvested rice is cut at a relatively high moisture content and must be dried before it can be stored. Since rice is marketed as a whole grain product, it is important that grains not be fractured or otherwise damaged before or during the drying process. Large column-type, continuous-flow dryers are widely used for rice drying. It usually requires two or more passes through the

TABLE 2-8. POTENTIAL SOURCES OF AIR EMISSIONS IN RICE MILLS[a]

I. Grain receiving and storage:	III. Mill house and loadout
1. Grain receiving	1. Disk huller
2. Rice handling	2. Husks aspirator
3. Grain dryer[b]	3. Paddy separator
	4. Brushes (whitening cones)
II. Cleaning house:	
1. Aspirators	IV. Packing and shipping
2. Separators	
3. Stoners	

[a]Reference 23.
[b]Includes on-farm drying upstream from mills.

dryers to reduce the moisture content to 12.0 percent to 13.5 percent, which is usually considered satisfactory for safe storage. Air volumes of 0.96 m^3/m^3 (120 ft^3/bu) of rice are commonly used. Rice drying is reported to generate a considerable amount of dust.

Preliminary cleaning of rice is sometimes done prior to drying. This preliminary cleaning can produce a significant reduction in dust emissions during the drying step.

Finished rice, marketed as U.S. No. 1 grade, must be dust-free. To achieve this grade, aspiration is used extensively in rice mills to remove dust as it is generated in the various milling steps (i.e., dust is not conveyed from one machine to another). As a result, all machinery in a rice mill is a source of some amount of dust. The most significant sources of dust are the scalpers, screens, sieves, disc separators, and shellers involved in the cleaning and handling of rough rice. The milling machines, pearlers, and brushes create bran dust. However, this dust is collected carefully because of its value as a byproduct.

2.3.2.4 Corn Dry Milling[23] Table 2-9 presents some of the more significant potential sources of air pollution in a corn dry mill. In most corn mills, the dust, small corn particles, spillage, etc., are collected as part of the processing operation and are saved for animal feed. Control devices for these processes are considered an integral part of the process equipment, and, strictly speaking, the control systems rather than the milling equipment are the emission points. Typically, several individual dust sources in both the receiving and processing areas are associated with a common control device.

Nearly all the operations associated with grain receiving and subsequent transfer to storage are potential emission sources. The grain unloading, cleaning, and drying steps are generally considered to be the main sources of air pollutants in this part of the mill complex.

One major difference between corn dry milling and other dry grain milling operations is the degerming and oil production stage. Because the oils are solvent extracted, this operation can be a source of VOC emission. These oil extraction operations are addressed in greater detail in AP-42 Section 9.11.1, Vegetable Oil Processing.

2.3.2.5 Animal Feed Mills[20,21,24] The ingredient receiving area represents the most serious dust emission problem in most feed mills. The truck and rail receiving stations present difficult dust control problems. The two principal factors that contribute to dust generation during bulk unloading are wind currents and dust generated when a falling stream of material strikes the receiving pit.

TABLE 2-9. POTENTIAL SOURCES OF AIR EMISSIONS IN A DRY CORN MILL[a]

I. Grain receiving, cleaning, and storage:	III. Milling section:
1. Grain receiving	1. Roller mills
2. Corn handling	2. Purifiers
3. Grain dryer	3. Aspirators
	4. Product dryers and coolers
II. Cleaning/Degerming section:	
1. Cleaner	IV. Byproducts and shipping:
2. Degerminator	1. Hammermill for extracted flakes and hulls
3. Degermer product dryers and coolers	2. Oil expeller
4. Aspirators	3. Bulk loading
5. Sifters	4. Packing station

[a]Reference 23.

The ingredient receiving area can be broken into separate areas, each with a specific set of dust control problems. These areas are:

1. Bulk receiving:
    a. Hopper rail car
    b. Hopper truck
    c. Straight truck
2. Materials handling equipment
3. Scales
4. Cleaning and scalping equipment.

The dust emission problems of the individual operations in each area parallel those discussed for the similar operations in grain elevators. However, in feed mills, a slower rate of materials handling is usually employed and a much wider range of materials may be handled. Factors affecting emission rates from the ingredient receiving area of a feed mill include the type of grain and other ingredients handled, the methods used to unload the ingredients, and the configuration of the receiving pits. Emissions from the materials handling and cleaning equipment are dependent primarily upon the cleanliness of the received material and the type of equipment used.

Hammermills, roller mills, cutters, and granulators are often used in the grain processing section of the feed mill and each can be a potential source of PM emissions. Dust emissions will vary with the type of grinder used (standard or full circle screens), the products being ground, the method of conveying finished product, and the type of control equipment used for product recovery.

Standard type hammermills utilizing 180-degree screens will normally require a minimum air flow through the screens in the range of 14 to 28 m^3/min (500 to 1,000 ft^3/min) per hammermill to maintain proper grinding action, eliminate back pressures in the mill, and remove heat. The full circle, or 360-degree screen, hammermill may or may not require air for proper grinding action. Normally, on coarse grinding, no air will be required. However, on fine grinding applications, air may be required to control internal temperatures even if dust emissions are not a problem. Both heat and dust can be controlled by adding more moisture during the grinding process.

Most grains being ground coarsely for mash-type feeds do not generate substantial quantities of dust. However, fine-grinding of grains, such as barley, wheat, and sorghum for pelleted-type feeds, can create dust problems.

The method of conveying the finished hammermill product has a major influence on dust emissions. Products from hammermills can be handled by:

1. Gravity systems (direct flow to bin);
2. Mechanical systems (conveyors and elevators);
3. Positive pressure pneumatic systems (high pressure);
4. Negative pressure pneumatic systems;
5. Fans attached to mill shaft (negative- and low-positive pressure); and
6. Separate fans located at the mill (negative- and low-positive pressure).

The gravity system will produce the least amount of dust emissions while the separate fan system will normally be the most "dusty" system.

Pellet mills are not a significant source of dust emissions. However, the pellet coolers are a source of dust, and they present control problems because of the moisture content of the airstream leaving the coolers. In a pellet cooler, the moisture content of the material is reduced from approximately 17 percent to 11 percent. The air flow rate in older mills ranges from 170 to 396 m^3/min (6,000 to 14,000 ft^3/min) in the coolers while in newer plants, air flow rates of 425 to 849 m^3/min (15,000 to 30,000 ft^3/min) are common.[23] A rule-of-thumb for estimating air flow rates through these units is 31 m^3/min/Mg (1,000 ft^3/min/ton) of pellets per hour.

While the bulk loadout of finished feed does not usually involve inherently dusty materials, loadout operations may still present a major source of PM emissions at feed mills. Bulk loading of trucks and railcars is done in a number of ways, all of which fall into two basic categories:

1. Gravity filling—material is moved by pneumatic or mechanical conveyor systems or discharged from overhead bins or scale hopper dropping directly into railcar or truck by gravity through a suitable connection.

2. Pneumatic filling—material is conveyed by air (positive pressure) directly to truck or railcar without use of a collector to separate air and material.

The main causes of dust emissions when loading bulk feed by gravity into trucks or railcars is the wind blowing through the loading sheds and dust generated when the falling stream of feed strikes the truck or railcar hopper. The wind velocity through loadout sheds and between bins is normally greater than that of the average wind velocity in open areas near the mill. Loading of bulk feed into railcars and trucks with a positive pressure system (pneumatic) requires a tightly closed system. Because the system must be tightly closed, the wind in the area has no effect on dust control.

2.3.2.6 Malted Barley Production[37-39] Emissions from malted barley production include: filterable PM (and PM-10 and PM-2.5) from barley unloading and handling operations and malt handling operations; filterable PM, condensable PM, organic compounds (including methane, volatile organic compounds, and other organic compounds), and combustion products from malt kilns; and SO_2 from facilities that burn sulfur into the kilns. Barley unloading operations are typically controlled by fabric filters. Malt kilns typically are not equipped with add-on control devices.

2.4 EMISSION CONTROL TECHNOLOGY[21,24,34,35]

The three general types of measures that are available to reduce emissions from grain handling and processing operations are process modifications designed to prevent or inhibit emissions, capture/ collection systems, and oil suppression systems that inhibit release of dust from the grain streams. Table 2-10 identifies the types of controls available for each source. The following paragraphs describe the general approaches to process controls, capture systems, and oil suppression. The characteristics of the collection systems most frequently applied to grain handling and processing plants (cyclones and fabric filters) are then described, and common operation and maintenance problems found in the industry are discussed.

Because emissions from grain handling operations are generated as a consequence of mechanical energy imparted to the dust by the operations themselves and local air currents in the vicinity of the operations, an obvious control strategy is to modify the process or facility to limit the effects of those factors that generate emissions. The primary preventive measures that facilities have used are construction and sealing practices that limit the effect of air currents and minimizing grain free fall distances and grain velocities during handling and transfer. Some construction and sealing practices that minimize emissions are enclosing the receiving area to the degree practicable, preferably with doors at both ends of a receiving shed; specifying dust-tight cleaning and processing equipment; using lip-type shaft seals at bearings on conveyor and other equipment housings; using flanged inlets and outlets on all spouting, transitions, and miscellaneous hoppers; and fully enclosing and sealing all areas in contact with products handled.[5]

A substantial reduction in emissions from receiving, shipping, handling, and transfer areas can be achieved by reducing grain free fall distances and grain velocities. Figure 2-10 illustrates a choke unloading procedure used to reduce free fall distance during hopper car unloading. The same principle can be used to control emissions from grain transfer onto conveyor belts and from loadout operations. An example of a mechanism that is used to reduce grain velocities is a "dead box" spout, which is used in grain loadout (shipping) operations. The dead box spout slows down the flow of grain and stops the grain in an enclosed area (Figure 2-11). The dead box is mounted on a telescoping spout to keep it close to the grain pile during operation. In principle, the grain free falls down the spout to an enclosed impact dead box, with grain velocity going to zero. It then falls onto the grain pile. Typically, the entrained air and dust liberated at the dead box is aspirated back up the spout to a dust collector. Finally, several different types of devices are available that, when added to the end of the spout, slow the grain flow and compress the grain discharge stream. These systems entrap the dust in the grain stream, thereby providing a theoretical reduction in PM emissions. There are few, if any, test data from actual ship or barge loading operations to substantiate this theoretical reduction in emissions.

While the preventive measures described above can minimize emissions, most facilities also require ventilation, or capture/collection, systems to reduce emissions to acceptable levels. In fact, air aspiration (ventilation) is a part of the dead box system described above. Almost all grain handling and processing facilities, except relatively small grain elevators, use capture/collection on the receiving pits, cleaning operations, and elevator legs. Generally, milling and pelletizing operations at processing plants are ventilated, and some facilities use hooding systems on all handling and transfer operations. An example of a capture/collection system at a truck receiving station is illustrated in Figure 2-12.

Grain elevators that rely primarily on aspiration typically duct many of the individual dust sources to a common dust collector system, particularly for dust sources in the headhouse. Thus, aspiration systems serving elevator legs, transfer points, bin vents, etc., may all be ducted to one collector in one elevator and to two or more individual systems in another. Because of the myriad possibilities for ducting, it is nearly impossible to characterize a "typical" grain elevator from the standpoint of delineating the exact number and types of air pollution sources and the control configurations for those sources.

The control devices typically used in the grain handling and processing industry are cyclones (or mechanical collectors) and fabric filters. Cyclones are generally used only on country elevators and small processing plants located in sparsely populated areas. Terminal elevators and processing plants located in densely populated areas, as well as some country elevators and small processing plants, normally use fabric filters for control. Both of these systems can achieve acceptable levels of control for many grain handling and processing sources. Although cyclone collectors can achieve acceptable performance in some scenarios, and fabric filters are highly efficient, both devices are subject to failure if they are not properly operated and maintained. Also, malfunction of the ventilation system can lead to increased emissions at the source.

The emission control methods described above rely on either process modifications to reduce dust generation or capture collection systems to control dust emissions after they are generated. An alternative control measure that has developed over the last 10 years is dust suppression by oil application. The

TABLE 2-10. PROCESS CONTROL AND EXHAUST SYSTEMS FOR GRAIN HANDLING AND PROCESSING[a]

Grain handling and processing operation	Potential control mechanism(s)[b]
Receiving	Grain flow control Capture/collection Total/partial enclosure
Belt conveyors	Enclosure Flow control Capture/collection Oil suppression Total/partial enclosure
Elevator legs	Capture/collection Oil suppression Total/partial enclosure
Distributors	Capture/collection Total/partial enclosure
Cleaners	Enclosure/exhaust
Scales	Enclosure/exhaust
Grain dryers	Screens Total/partial enclosure
Hammermills	Capture/collection Total/partial enclosure
Roller mills	Capture/collection Total/partial enclosure
Mixers	Capture/collection Total/partial enclosure
Truck/rail loadout	Dust suppression Capture/collection Oil suppression Total/partial enclosure
Barge/ship loadout	Dust suppression Capture/collection Oil suppression Total/partial enclosure

[a]Source: References 24, 48, and 49.
[b]Capture/collection refers to a forced ventilation system consisting of a capture device (hood or enclosure) connected via ductwork to a dust collector.

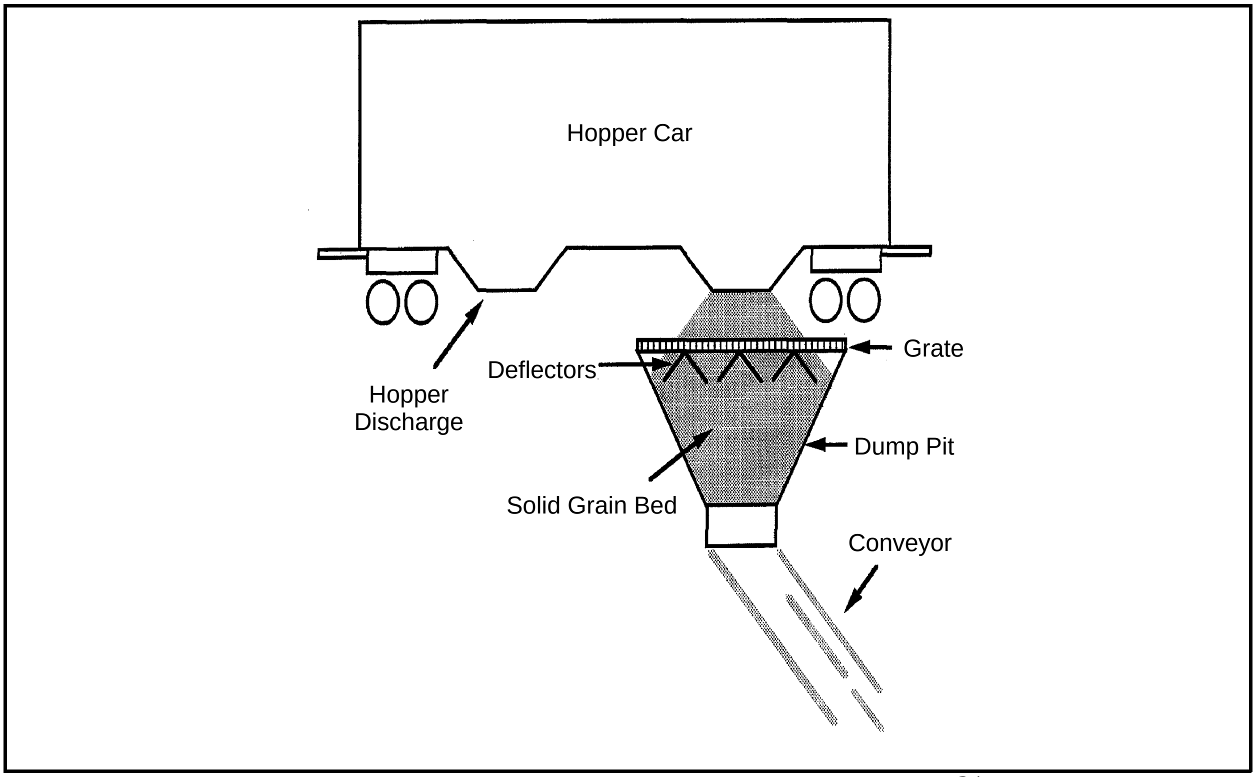

Figure 2-10. Choke unloading for a grain receiving process.[24]

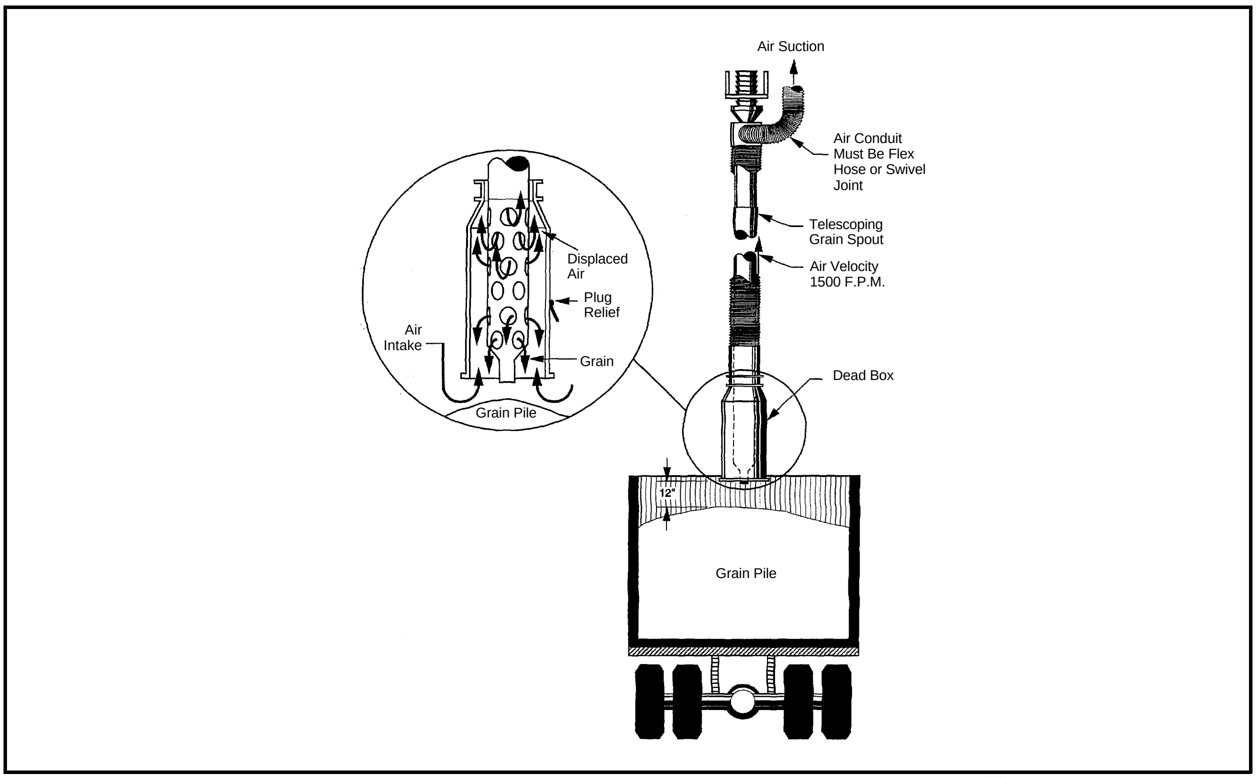

Figure 2-11. Dead box for reducing loading/shipping emissions.[24]

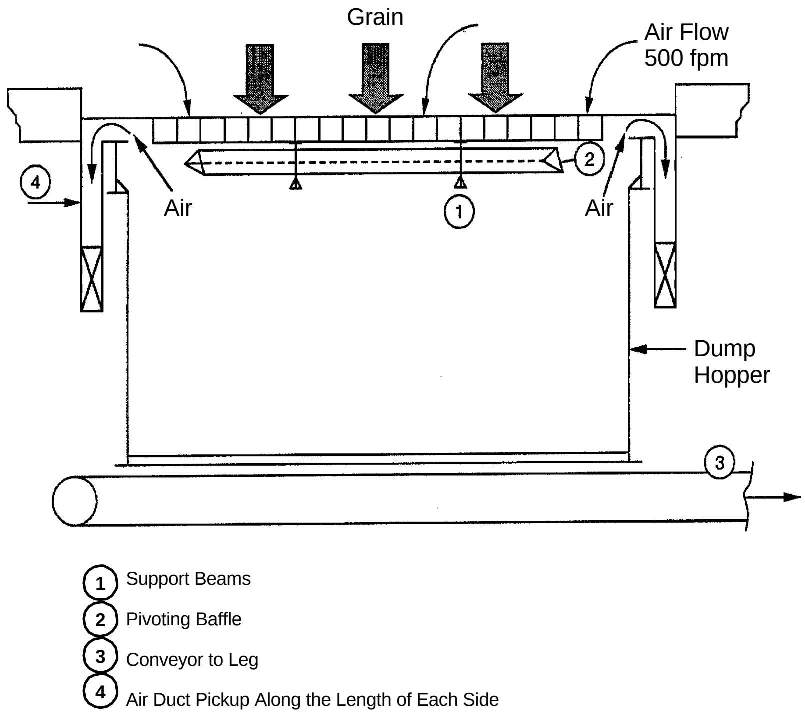

Figure 2-12. Receiving pit capture/collection (ventilation) system.[24]

driving forces for developing most such dust suppression systems have been grain elevator explosion control as well as emission control. Consequently, few data have been published on the amount of emission reduction achieved by such systems. Recent studies, however, have indicated that a PM reduction of approximately 60 to 80 percent may be achievable (see References 57 and 61 in Section 4).

Generally, these oil application dust suppression systems use either white mineral oil, soybean oil, or some other vegetable oil. Currently the Food and Drug Administration restricts application rates of mineral oil to 0.02 percent by weight. Laboratory testing and industry experience have shown that oil additives applied at a rate of 60 to 200 parts per million by weight of grain, or 0.5 to 1.7 gallons of oil per thousand bushels of grain can provide effective dust control.[36] The effectiveness of the oil suppression system depends to some extent on how well the oil is dispersed within the grain stream after it is applied. Several options are available for applying oil additives.

1. As a top dressing before grain enters the bucket elevator or at other grain transfer points.
2. From below the grain stream at a grain transfer point using one or more spray nozzles.
3. In the boot of the bucket elevator leg.
4. At the discharge point from a receiving pit onto a belt or other type conveyor.
5. In a screw conveyor.

REFERENCES FOR SECTION 2

1. Mark S. Carleton, *The Small Grains*, The MacMillan Company, NY, 1923.

2. Donald C. Rasmusson (ed), *Barley*, American Society of Agronomy, Crop Science Society of America, Soil Society of America, Madison, WI, 1985.

3. R. F. Peterson, *Wheat*, Interscience Publishers, Inc, NY, 1965.

4. S. K. De Datta, *Principles and Practices of Rice Production*, John Wiley and Sons, NY, 1981.

5. A. V. Myasnihora, Y. S. Rall, L. A. Trisvyatskii, and I.S. Shatilor, *Handbook of Food Products--Grain and Its Products*, Israel Program for Scientific Translations, Jerusalem, Israel, 1969.

6. Samuel R. Aldrich, Walter O. Scott, and Robert G. Hoeft, *Modern Corn Production*, Third Edition, A. & L. Publications, Champaign, IL, 1986.

7. Walter Bushuk, *Rye: Production, Chemistry, and Technology*, American Association of Cereal Chemists, St. Paul, MN, 1976.

8. Francis H. Webster, *Oats: Chemistry and Technology*, American Association of Cereal Chemists, St. Paul, MN, 1986.

9. Samuel A. Matz, *Cereal Science*, Avi Publishing Co., Westport, CT, 1969.

10. *The World Book Encyclopedia*, Chicago, 1992.

11. *Farms and Land in Farms*, U.S. Department of Agriculture, Agricultural Statistics Board, National Agricultural Statistics Service, July, 1996.

12. D.B. Brooker, F.W. Bakker—Arkema, and C.W. Hall, *Drying and Storage of Grains and Oil Seeds*, Van Nostrand Reinhold, New York, NY, 1992.

13. *Crop Production Annual Summary*, U.S. Department of Agriculture, Agricultural Statistics Board, National Agricultural Statistics Service, January, 1997.

14. *Grain Stocks*, U.S. Department of Agriculture, Agricultural Statistics Board, National Agricultural Statistics Service, January, 1997.

15. V. Ramanthan and D. Wallace, *Review of Compliance Monitoring Programs with Respect to Grain Elevators*, Final Report, EPA Contract 68-01-4139, Tasks 12 and 14, Midwest Research Institute, March 1980.

16. *Transportation of U.S. Grains, A Model Share Analysis*, USDA-AMS. U.S. Department of Agriculture, July 1992.

17. Statistical Summaries, *Milling Directory, Milling and Baking News*, p. 9, 1992.

18. 1992 Census of Manufactures, *Grain Mill Products*, U.S. Department of Commerce, June 1995.

19. 1987 Census of Manufactures, *Fats and Oils*, U.S. Department of Commerce, December 1989.

20. *Source Category Survey: Animal Feed Dryers*, EPA-450/3-81-017, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1981.

21. R. L. McElhiney, *Feed Manufacturing Technology III*, American Feed Manufacturers Association, Arlington, VA, 1985.

22. Facsimile from Brian Bursiek, American Feed Industry Association, Washington, D.C., to Tom Lapp, Midwest Research Institute, Cary, NC, October 6, 1997.

23. L. J. Shannon, *et al*., *Emissions Control in the Grain and Feed Industry, Volume I: Engineering and Cost Study*, EPA-450/3-73-003a, U.S. Environmental Protection Agency, Research Triangle Park, NC, December 1973.

24. D. Wallace, *Grain Handling and Processing*, Part of Chapter 13, "Food and Agricultural Industry," in *Air Pollution Engineering Manual*, Van Nostrand Reinhold, NY, 1992.

25. Letter from Thomas C. O'Connor, National Grain and Feed Association to Dallas Safriet, U. S. Environmental Protection Agency, Research Triangle Park, NC. November 24, 1993.

26. Bienvenido O. Juliano. *Rice Chemistry and Technology,* American Association of Cereal Chemists. St. Paul, MN, 1985.

27. Bor S. Luk. *Rice*, Volume I, Production, Second Edition, Van Nostrand Reinhold, New York, NY, 1991.

28. Bor S. Luk. *Rice*, Volume II, Utilization, Second Edition, Van Nostrand Reinhold, New York, NY, 1991.

29. G. F. Spraque and J. W. Dudley, *Corn and Corn Improvement*, Third Edition, American Society of Agronomy, Inc., Crop Science Society of America, Inc., and Soil Science Society of America, Inc., Madison, WI, 1988.

30. S. A. Watson and P. E. Ramstad. *Corn Chemistry and Technology*, American Association of Cereal Chemists, Inc., St. Paul, MN, 1987.

31. Letter from Brian Bursiek, American Feed Industry Association to Dallas Safriet, U. S. Environmental Protection Agency, Research Triangle Park, NC. October 27, 1993.

32. R. A. Wachter and T. R. Blackwood, *Source Assessment: Harvesting of Grain, State of Art*, EPA-600/2-77-107f, U.S. Environmental Protection Agency, Research Triangle Park, NC, 1977.

33. Health and Hygiene, Inc. *Worker Exposure to Dust in the Grain Industry*. Unpublished report for the National Grain and Feed Association. September, 1991.

34. H. D. Wardlaw Jr., C. B. Parnell Jr., and B. J. Leschar, *Dust Suppression Results with Mineral Oil Applications for Corn and Milo*, Transactions of the American Society of Agricultural Engineers, 1989.

35. F. S. Lai, *et al*., *Reducing Grain Dust with Oil Additives*, Transactions of American Society of Agricultural Engineers, 1981.

36. Letter from Thomas C. O'Connor, National Grain and Feed Association to Dallas Safriet, U.S. Environmental Protection Agency, Research Triangle Park, NC. June 30, 1997.

37. *Compliance Test Report for the Determination of Nonmethane Organic Compound Emissions from the No. 15 Kiln Malt Dryer Exhaust, Prepared for Ladish Malting Company, Jefferson Junction, WI,* Fluid Management, Inc., Milwaukee, WI, December 1995.

38. H. J. Beaulieu, *Final Report Atmospheric Emission Testing Busch Agricultural Resources, Inc. Idaho Falls Malt Plant*, Industrial Hygiene Resources, Ltd., Boise, Idaho, October, 1991.

39. M. J. Huenink, *Total Particulate Emissions Stack Testing of the Kiln 6 Operations at Busch Agricultural Resources, Inc., Manitowoc, Wisconsin*, Environmental Technology & Engineering Corp., Elm Grove, Wisconsin, May 8, 1996.

3. GENERAL DATA REVIEW AND ANALYSIS PROCEDURES

3.1 LITERATURE SEARCH AND SCREENING

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 Factor and Inventory Group (EFIG) were reviewed for information on the industry, processes, and emissions. The Factor Information and Retrieval (FIRE), 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 for identification of the 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 data bases.

Information on the industry, including number of plants, plant location, and annual production capacities, was obtained from the United States Department of Agriculture (USDA), the *Census of Manufactures* and other sources. 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 grain elevator and grain processing industry. However, no test reports were located using the TSAR data base. The EPA library was searched for additional test reports. Using information obtained on plant locations, individual facilities and state and Regional offices were contacted about the availability of test reports. Publications lists from the Office of Research and Development (ORD) and Control Technology Center (CTC) were also searched for reports on emissions from the grain elevator and grain processing industry. In addition, representative trade associations, including the National Grain and Feed Association (NGFA), and National Cattleman's Beef Association, were contacted for assistance in obtaining information about the industry and emissions.

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 should contain test results based on more than one test run. If results from only one run are presented, the emission factors must be down rated.

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 DATA QUALITY RATING SYSTEM[1]

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 half);

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 EFIG for preparing AP-42 sections. The data were rated as follows:

A—Multiple test runs that were performed 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 unproven or new methodology or that lacked a significant amount of background information.

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. <u>Source operation</u>. 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. <u>Sampling procedures</u>. 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. <u>Sampling and process data</u>. 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[1]

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

A—Excellent: Developed from A- and B-rated source 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- or 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 industries. The source category is specific enough so that variability within the source category population may be minimized.

C—Average: Developed only from A-, B- and/or C-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-, B-, and/or C-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 footnoted.

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 Section 4.

REFERENCE FOR SECTION 3

1. *Procedures for Preparing Emission Factor Documents*, EPA-454/R-95-015, U. S. Environmental Protection Agency, Research Triangle Park, NC, May 1997.

4. AP-42 SECTION DEVELOPMENT

This section describes the test data and methodology used to update pollutant emission factors for the interim AP-42 Section 9.9.1, Grain Elevators and Processes. This update was the result of a review and analysis of the data base used to formulate the current emission factors and of new data obtained during the literature search. Excerpts from the various tests reports and calculations used to reduce the data to an appropriate format for emission factor development are contained in Appendices B through EE.

4.1 REVIEW OF SPECIFIC DATA SETS

During the literature search, 65 documents that contained information about grain handling emissions were collected and reviewed. Two additional documents on analyzing particle size data were also reviewed. These documents are listed in the references at the end of this section. The list of references also indicates whether the report contains emission data that are used for emission factor development.

The original group of documents were reduced to a final set of 37 primary reports using the criteria outlined in Section 3.1. For those documents not used, Table 4-1 summarizes the basis for their rejection. The data contained in each of these 37 primary references by number are described below. All raw test data (and subsequent calculations, if required) are presented in the units in which they were originally published.

4.1.1 Reference 4 (1987)

Reference 4 consists of correspondence between the Purina Mills company and U. S. EPA. Attached to this correspondence were portions of PM source test reports for five feed mills operated by Purina. Triplicate EPA Method 5 tests were conducted for filterable PM at the cyclone outlet for a variety of feed mill processes (and also at the cyclone inlet for one process).

At Mill No. 1, tests were conducted on the outlet ducts for two pellet mill coolers, one producing steer feed and one poultry feed, and on the outlet duct of a rolling unit that crimps grains used in feed mix. The rolling unit was processing corn and barley during the test. The steer pellet unit was controlled by a Longhorn cyclone in parallel with two Carter-Day cyclones in series, the poultry pellet unit was controlled with two cyclones in parallel, and the rolling unit was controlled by a single cyclone.

At Mill No. 2, tests were conducted on a pellet cooler producing mixed feed and on a corn cracker. The excerpts from the test report contained no information about the process, but a summary table attached to the letter from Purina did indicate that both operations were controlled with cyclones. However, the type of cyclone is unknown, and some of the data in the test report excerpts cannot be clearly tied to a specific process.

At Mill No. 3, results were reported for four pellet coolers, two producing steer feed and two producing poultry feed. Again, the test report excerpts contained no information about the processes or control systems, but the summary table did indicate that emissions from each unit were controlled with a cyclone system. The test report excerpts indicated that tests were also conducted on the railcar unloading operations and that emissions were problematic. However, no data were included in the information supplied by Purina. Information from Purina supplied by telephone indicated that only concentrations were measured at the railcar unloading stations so emission rates could not be determined.

TABLE 4-1. DOCUMENTS NOT INCLUDED IN EMISSION FACTOR DEVELOPMENT

Ref. No.	Cause(s) for rejection
1	Background document for 1988 revision to Section 6.4—that contained no original data; however, primary references from Reference 1 were reviewed as a part of this study.
2	Unsubstantiated emission factors submitted in response to Section 6.4 revisions in 1987 with no original test data. Because the origin of the data could not be determined and quality ratings could not be assigned, they were not considered in the emission factor development.
3	Undocumented test data; neither source characteristics nor test procedures were adequately documented to rate data.
5	Not original source of test data; used to develop process description.
7	Emissions for corn wet milling; not applicable to this section, but report excerpts retained in Appendix D for reference.
8	Not original source of test data; used to develop emission control technology descriptions.
9	Not original source of test data; used to characterize industry and develop process descriptions and control technology discussion.
13	Secondary data from other sources with no original data and no information specific to grain handling and processing; not used in this study.
14	Contains no emission data; dated information on grain fumigants only; not used for this study.
15	Emissions data for coal-fired boiler; not applicable to this section.
16	Emissions for grain harvesting not grain processing; not applicable to this section.
17	Contains no direct emission data; emission estimates could not be verified so they were not used in subsequent analyses.
18	Undocumented test data; neither source characheristics nor test procedures were adequately documented to rate data. Selected paged retained in Appendix E for reference.
19	General process descriptions only; not used for this study.
20	Insufficient process data to calculate emission factors; Appendix C contains emission rates but no process rates; EMB files searched for original references.
21	Background report for emission factors for Section 6.4 in earlier AP-42 edition—no original test data; original references reviewed if they could be located.
23	APCD inlet data only; it is generally agreed that emissions data measured at the inlet side of a dust control device cannot be used as an accurate estimate of uncontrolled emissions; data not used in this study.
24	APCD inlet data only; it is generally agreed that emissions data measured at the inlet side of a dust control device cannot be used as an accurate estimate of uncontrolled emissions; data not used in this study.
28	Background report for emission factors for Section 6.4 in earlier AP-42 edition—no original test data; original references reviewed if they could be located.
29	Not original source of test data; inventory estimates based on emission factors from Reference 28.
30	APCD inlet data only; it is generally agreed that emissions data measured at the inlet side of a dust control device cannot be used as an accurate estimate of uncontrolled emissions; data not used in this study.
31	No useful data.

TABLE 4-1. (continued)

Ref. No.	Cause(s) for rejection
32	No air emission data; good process description for milling plants.
34	No process data; cannot determine emission factor.
44	No test method specified; data are 27 years old and are not considered reliable.
45	Comments on draft Background Document and AP-42 Section; no test data.
59	Insufficient process data to calculate emission factors in units of kg/Mg (lb/ton); only one valid test run.
62	Concentration data only, no emission rates; data are 18 years old and may not be representative of current elevator operations.
63	Secondary data from other sources and undocumented test data; neither source characteristics nor test procedures were adequately documented to rate data; not used in this study.
64	Undocumented test data; neither source characteristics nor test procedures were adequately documented to rate data.
65	Insufficient process data to calculate emission factors in units of kg/Mg (lb/ton); source characteristics not adequately documented to rate data.

The test results reported for Mill No. 4 are those from Reference 38, which is the original test report. Consequently, they are not included here.

At Mill No. 5, tests were conducted at the exhaust stack of a pellet cooler operation that was processing hog chow and horse feed. Emissions were controlled by three cyclones operating in series.

Although the information contained in Reference 4 was not fully documented, the data were considered in the development of candidate emission factors. A summary of the test results for Mills No. 1, 2, 3, and 5 are shown in Table 4-2. The data for Mill No. 4 is included with the discussion of Reference 38.

Appropriate methods appear to have been used to collect the data presented in Reference 4, and the data generally appear to be of adequate quality for emission factor development. However, the lack of documentation of some of the process information and the testing methodology affected data quality ratings. For Mill No. 1, process information was reasonably complete and test methods were adequately described. However, because field and laboratory data were not documented, the data could not be rated A. For the steer feed cooler and the rolling unit, the data are rated B. The data for the poultry feed cooler are rated C because only one of the two exhaust stacks was tested. For Mill No. 2, process data are quite limited, and no documentation of the field and laboratory data is provided. Furthermore, stack flow problems that may be indicative of cyclonic flow were noted for both operations. Consequently, the data are rated C. Because no process information is supplied for Mill No. 3, these data are also rated C. The data for Mill 5 are rated B. Applicable report excerpts and calculations are provided in Appendix B.

4.1.2 References 6, 10, and 12 (1984, 1979, and 1978)

References 6 and 10 are reports of fugitive PM emission testing and subsequent emission factor development for shiploading operations at four grain export elevators. The concentration of respirable dust (i.e., particles approximately 5 µm or less in aerodynamic diameter) was determined using a

TABLE 4-2. SUMMARY OF PM EMISSION DATA FROM REFERENCE 4

Mill No.	Emission source	Test location relative to cyclone collector	Average particulate emission rate		Average process weight rate[a]		Calculated emission factor[b]	
			kg/hr	lb/hr	kg/hr	lb/hr	kg/Mg	lb/ton
1	Steer pellet cooler	outlet	4.5	10.0	10,900	24,000	0.417	0.833
	Poultry pellet cooler	outlet	5.0	11.0	10,900	24,000	0.458	0.917
	Flaking machine (corn/barley)	outlet	0.4	0.9	5,400	12,000	0.075	0.15
2	Pellet cooler (Test No. 1)	outlet	0.1998	0.4404	9,100	20,000	0.0220	0.0440
	Grain cracker (corn)		0.0440	0.0969	3,600	8,000	0.0121	0.0242
3	W. poultry pellet cooler	outlet	3.3	7.2	13,000	28,800	0.250	0.500
	E. poultry pellet cooler	outlet	1.8	4.0	13,000	28,600	0.140	0.280
	High steer pellet cooler	outlet	1.8	3.9	11,100	24,400	0.160	0.320
	Low steer pellet cooler	outlet	3.3	7.3	13,500	29,800	0.245	0.490
5	Pellet cooler	outlet	0.575	1.27	7,190	15,850	0.081	0.162[c]

[a]Taken directly from available documentation except for Mills 3 and 4 for which the process rate was calculated from the emission rate and the emission factor provided in the documentation.
[b]Calculated from data in previous two columns except for Mills 3 and 5 for which emission factors were presented in the available documentation.
[c]Triple cyclone outlet.

GCA RDM-101 beta attenuation instrument with the aerodynamic particle size distribution determined using an Andersen cascade impactor.

Except in one instance, sampling was conducted at a single point in the plume downwind of the entrance to the ship hold during uncontrolled loading, tent-controlled loading, and dead-box-controlled loading operations. The extent of the dust plume sampled, which was estimated visually, was later used to determine the PM emission rate from the point concentration measurements. Table 4-3 summarizes the particle size data as calculated from the raw experimental data.

Reference 12 reports a related study to assess the potential explosion hazard from grain dust during the tent-controlled loading of wheat into a bulk carrier ship. Dust concentrations (less than about 75 to 100 µm) were measured at various points in the hold. Two particle sizing tests were also performed during tent-controlled loading and uncontrolled loading (topping-off) operations. No emission rates or factors were developed in this portion of the study, but the relative concentrations provide some indication of the control level that might be achieved by different operation rates. Tables 4-4 and 4-5 summarize the measured dust concentrations and particle sizing data, respectively, as taken directly from pages 18 and 11 of Reference 12.

The data contained in References 6, 10, and 12 were only minimally documented with no information provided on instrument calibration, gravimetric analysis of impactor catches, raw field data, etc. Also, in the case of the downwind fugitive measurements, single point sampling was generally conducted to characterize the entire dust plume from the source. Because these data were collected using a test methodology which no longer meets EPA acceptance, these data were not incorporated into the AP-42 section and are not discussed further in this report. Selected pages from all three reports are provided in Appendix C.

4.1.3 Reference 11 (1979)

Reference 11 is a study of the fine particle emissions from a variety of source categories in the South Coast Air Basin (Los Angeles) sponsored by the California Air Resources Board (CARB). Two of the tests conducted in this study were of the uncontrolled emissions from a rice dryer and a carob roaster using one or more types of series cyclone sampling trains that were designed for particle sizing (Joy train and/or Source Assessment Sampling System or SASS). For each test only one run using each train was conducted in conjunction with these tests. Data on both particle size distribution and chemical composition of the collected PM were obtained. Information obtained as a part of this AP-42 revision indicates that rice properties have changed substantially over the past 20 years, and that these changes have had a significant impact on the emission potential of rice dryers.[50] Consequently, the rice dryer data in Reference 11 are considered unratable for purposes of AP-42 emission factor development, and are not used in the development of rice dryer emission factors. Selected pages from the report are retained in Appendix D for reference.

4.1.4 Reference 22 (1976)

Reference 22 is the report of PM compliance tests conducted at a country grain elevator in North Dakota. Triplicate EPA Method 5 measured the emissions from cyclone dust collectors serving the headhouse (internal grain handling) and two grain cleaners during the processing of wheat (assumed based on the grain density of 770 kg/m^3 [60-lb/bu]) provided in the report). The exact emission points included in the headhouse dust control system were not specified in the report, but analysis of the process description suggested that dust pick-up points were located at the truck dump, the legs, various belt

TABLE 4-3. RESULTS OF DOWNWIND ANDERSEN IMPACTOR MEASUREMENTS DURING SHIP LOADING[a]

Facility tested	Control	Test duration, min	Total measured concentration, mg/m^3 (10^{-3} grains /dscf)	Size distribution, concentration in size range, mg/m^3 (10^{-3} grains/dscf)[b] µm: >13.5	11.2-13.5	7.7-11.2	5.2-7.7	3.3-5.2	1.67-3.3	1.04-1.67	0.71-1.04	<0.71
Bunge	Tent	37	89 (38.9)	54.8 (23.9)	4.8 (2.10)	7.4 (3.23)	7.7 (3.36)	7.1 (3.10)	5.0 (2.18)	1.5 (0.655)	0.0 (0.0)	0.6 (0.262)
Dreyfus	Tent	32	200 (87.4)	142 (62.0)	18.6 (8.13)	15.8 (6.90)	10.0 (4.37)	10.4 (4.54)	4.8 (2.10)	3.4 (1.49)	1.0 (0.437)	3.2 (1.40)
Cargill-1	Dead-box	62	9.3 (4.1)	5.9 (2.58)	0.18 (0.079)	1.1 (0.481)	0.19 (0.083)	0.53 (0.232)	0.35 (0.153)	0.53 (0.232)	0.36 (0.157)	0.18 (0.079)
Cargill-2	None	62	95 (41.5)	33.8 (14.8)	9.7 (4.24)	12.1 (5.29)	8.6 (3.76)	25.4 (11.1)	3.7 (1.62)	1.1 (0.481)	0.38 (0.166)	1.9 (0.830)
Columbia-1	None	25.4	104 (45.4)	39.3 (17.2)	14.4 (6.29)	10.4 (4.54)	15.6 (6.82)	11.8 (5.16)	9.6 (4.19)	2.6 (1.14)	0.42 (0.184)	0.0 (0.0)
Columbia-2	None	34	135 (59.0)	60.5 (26.4)	10.0 (4.37)	20.9 (9.13)	13.5 (5.90)	12.0 (5.24)	9.0 (3.93)	5.8 (2.53)	2.6 (1.14)	0.68 (0.297)
Calculated average concentration (mg/m^3)[c]			105 (45.9)	56.1 (24.5)	9.61 (4.20)	11.3 (4.94)	9.26 (4.05)	11.2 (4.89)	5.41 (2.36)	2.49 (1.09)	0.793 (0.347)	1.09 (0.476)
Calculated percent of total concentration[d]			100 (43.7)	53 (23.2)	9.2 (4.02)	11 (4.81)	8.8 (3.84)	11 (4.81)	5.2 (2.27)	2.4 (1.05)	0.76 (0.332)	1.04 (0.454)

[a]Source: pp. 15-28 of Reference 10. Tests include processes with no controls and with control systems.
[b]Micrometers (µm) aerodynamic diameter (equivalent unit density spheres).
[c]Arithmetic average concentrations calculated from data in each particle size range shown in column above; because size distribution were comparable, uncontrolled and controlled emissions combined to estimate particle size distributions.
[d]Weight percent of total concentration in each size range.

TABLE 4-4. SUMMARY OF SHIP HOLD DUST CONCENTRATIONS[a,12]

Conditions		No. of runs	Average concentration measured (time-weighted)		Maximum long-term average concentration		Maximum estimated average concentration	
			g/m³	grains/dscf	g/m³	grains/dscf	g/m³	grains/dscf
Tents in use-Aspiration rate: 225 m^3/min (7,946 dscf/min)		6	0.29	0.13	0.87	0.38	2.3	1.00
-Aspiration rate:	160 m^3/min (5,650 dscf/min)	8	0.32	0.14	0.67	0.29	1.0	0.44
-Aspiration rate:	0 m^3/min (0 dscf/min)	4	0.86	0.38	0.83	0.36	(2.2)[b]	(0.96)[b]
Tents not in use		8	0.18	0.09	0.75	0.33	(1.7)[c]	(0.74)[c]

[a]Loading of wheat into a bulk carrier.
[b]Questionable value. The next highest estimated 1-min average concentration in this body of data is 1.5 g/m^3 (0.66 grains/dscf).
[c]Questionable value. The next highest estimated 1-min average concentration in this body of data is 1.0 g/m^3 (0.44 grains/dscf).

TABLE 4-5. PARTICLE SIZE DISTRIBUTIONS FOR DUST GENERATED IN HOLD DURING SHIP LOADING OF WHEAT[12]

Test condition	Sampling time, min	Total dust concentration		Weight percent less than stated size[a]							
		g/m³	grains/dscf	Cyclone	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
Tent control	7	0.29	0.13	70.5 (19.6)	57.2 (16.4)	39.0 (11.2)	34.5 (7.63)	24.5 (4.75)	17.0 (2.10)	8.70 (1.44)	1.74 (0.883)
Uncontrolled[b]	7	0.18	0.09	68.3 (18.4)	62.6 (15.4)	44.7 (10.5)	28.2 (7.16)	19.1 (4.46)	9.72 (1.96)	5.64 (1.35)	0 (0.825)

[a]Numbers in parentheses are stage cut-points in μm aerodynamic diameter. Top numbers are weight percentages less than stated sizes.
[b]During topping-off operations.

transfer points, and the weigh scale system. Note that some systems of this type include the truck dump and some do not. In older elevators, the capture/collection system for truck unloading was added later and thus, is vented through a separate dust collector. A summary of the test results for the controlled emissions from the cyclones are shown below:

- Average headhouse emissions: $\frac{0.71 \text{ lb/hr}}{150 \text{ ton/hr}}$ = 0.0047 lb/ton (0.0023 kg/Mg)
- Average Crippen cleaner emissions: $\frac{0.37 \text{ lb/hr}}{13 \text{ ton/hr}}$ = 0.029 lb/ton (0.015 kg/Mg)
- Average Ideal cleaner emissions: $\frac{0.25 \text{ lb/hr}}{27 \text{ ton/hr}}$ = 0.0093 lb/ton (0.0046 kg/Mg)

Reference 22 contained excellent documentation of the test protocol, results, raw data collected, and appropriate QA/QC. However, because insufficient data were available with respect to the composition of the headhouse dust collection system to identify emission points with certainty, the data headhouse were given a B rating using the criteria specified in Section 3. The data for the cleaner tests were rated B because the grains processed were not specified. Applicable pages from the test report are provided in Appendix F.

4.1.5 Reference 25 (1976)

Reference 25 reports PM compliance test results for the headhouse and grain cleaner of a North Dakota country elevator. Duplicate (or triplicate) tests were conducted at the inlet and outlet of cyclone dust collectors serving each system using EPA Method 5 procedures. The headhouse dust collection system comprised seven pick-up points: grain distributor; scale; front and back pits; two legs; and floor sweeps on each floor of the elevator. Summary data for the tests conducted are shown in Table 4-6.

It is generally agreed that emission measurements taken at the inlet of a control device do not accurately reflect emissions from uncontrolled sources. It is agreed that the emission estimates based on control device inlet data are biased high for uncontrolled emissions at operations not equipped with aspiration systems. Therefore, the control device inlet data in this report have not been used to estimate uncontrolled emissions.

The information contained in Reference 25 was poorly documented with no raw data, calculations, calibration data, etc. Also, one of the tests was performed at a sampling rate that does not meet applicable Method 5 criteria. Based on these limitations, a rating of C was assigned to the emissions data contained in Reference 24. Applicable portions of the test report are provided in Appendix G.

4.1.6 Reference 26 (1975)

Reference 26 is a technical paper presented at a local meeting of the Air Pollution Control Association (now the Air and Waste Management Association) that characterizes emissions from grain receiving, handling, and shipping operations at country and subterminal elevators located in eastern Washington. Although technical papers are usually not used for emission factor development, this particular paper is the original publication of these data, and the results were included in the analyses. The tests were performed using EPA Method 5 techniques with limited particle sizing performed using an

TABLE 4-6. SUMMARY OF TOTAL PM EMISSION DATA FROM REFERENCE 25

Test location	Test No.	PM emission rate		Grain process weight rate		Total PM emission factor[a]	
		kg/hr	lb/hr	Mg/hr	ton/hr	kg/Mg	lb/ton
Cleaner cyclone No. 1 inlet	1	5.0	11.0	24.8	27.3	0.20	0.40
	2	3.7	8.1	26.1	28.8	0.14	0.28
	3	1.2	2.6	19.6	21.6	0.060	0.12
	Average[b]	3.3	7.2	23.5	25.9	0.14	0.27
Cleaner cyclone No. 2 inlet[c]	2	2.3	5.0	24.8	27.3	0.092	0.18
	3	1.2	2.7	27.5	30.3	0.045	0.089
	Average[b]	1.8	3.9	26.1	28.8	0.070	0.14
Cleaner cyclone No. 1 outlet	1	2.1	4.6	24.8	27.3	0.084	0.17
	2	0.95	2.1	26.1	28.8	0.037	0.073
	3	0.68	1.5	19.6	21.6	0.035	0.069
	Average[b]	1.2	2.7	23.5	25.9	0.052	0.10
Cleaner cyclone No. 2 outlet[c]	2	0.77	1.7	24.8	27.3	0.031	0.062
	3	0.73	1.6	27.5	30.3	0.027	0.053
	Average[b]	0.75	1.6	26.1	28.8	0.029	0.057
Headhouse cyclone inlet	1	4.0	8.8	76.4	84.2	0.052	0.10
	2	4.0	8.9	86.3	95.1	0.047	0.094
	Average[b]	4.0	8.8	81.4	89.7	0.049	0.098
Headhouse cyclone outlet	1	2.6	5.8	76.4	84.2	0.035	0.069
	2	2.9	6.3	86.3	95.1	0.033	0.066
	Average[b]	2.8	6.1	81.4	89.7	0.034	0.068

[a]Calculated from data in previous two columns. Note that the emission factors for cleaner cyclone 1 and 2 must be added together to obtain the total emission factor for the unit. Cleaner inlet = 0.21 kg/Mg (0.41 lb/ton); cleaner outlet = 0.079 kg/Mg (0.157 lb/ton).
[b]Calculated from test data shown in column above.
[c]Data for Test No. 1 deleted due to isokinetic sampling rate of 151 percent.

unspecified cascade impactor. A summary of the PM emission factors obtained in the study are shown below:

- Country elevators:
  - Uncontrolled receiving: 0.020 kg/Mg (0.040 lb/ton) (wheat); 3.4 kg/Mg (6.8 lb/ton) (lentils)
  - Uncontrolled handling: 3.6 kg/Mg (7.1 lb/ton) (peas)
  - Uncontrolled receiving and handling: 0.08 kg/Mg (0.16 lb/ton) (wheat); 7.0 kg/Mg (14 lb/ton) (lentils)
  - Controlled handling (cyclone): 0.075 kg/Mg (0.15 lb/ton) (peas)
  - Controlled receiving and handling (cyclone): 0.35 kg/Mg (0.71 lb/ton) (lentils)

- Subterminal elevators:
  - Uncontrolled receiving: 0.39 kg/Mg (0.77 lb/ton) (wheat)
  - Uncontrolled handling: 0.24 kg/Mg (0.49 lb/ton) (wheat)
  - Uncontrolled receiving and handling: 0.027 kg/Mg (0.054 lb/ton) (wheat)
  - Controlled receiving (cyclone): 0.0047 kg/Mg (0.0094 lb/ton) (wheat)
  - Controlled handling (cyclone): 0.0055 kg/Mg (0.011 lb/ton) (wheat)
  - Controlled receiving and handling (cyclone): 0.0050 kg/Mg (0.010 lb/ton) (wheat)

Although data contained in Reference 26 seem to be of fairly good quality, a high degree of variability is exhibited from elevator to elevator. In addition, very little documentation was provided in the paper to define the characteristics of the sources tested, the test procedures used, etc. For this reason, a rating of C was assigned to the above data. Excerpts from the paper as well as the calculations performed on the particle size data are provided in Appendix H.

4.1.7 Reference 27 (1974)

Reference 27 reports PM performance test results for a North Dakota country elevator. Duplicate tests were conducted at the inlet and outlet of cyclone dust collectors serving the headhouse dust control system and two types of grain cleaners using a version of American Society of Mechanical Engineers (ASME) Power Test Code (PTC) 27. (Note that PTC 27 is similar to EPA Method 17 but, depending on the specific sampling equipment used and test conditions, does not necessarily provide equivalent results.) The headhouse dust control system contained pick-up points throughout the interior of the elevator including leg boots and heads; front truck dump pit and two back pits; boot sweeps; and bin and scale vents (scale vents were closed during testing). The data obtained in the study are summarized below:

- House dust control cyclone: 0.031 kg/Mg or 0.062 lb/ton (inlet); 0.0056 kg/Mg or 0.011 lb/ton (outlet)

- Ideal grain cleaner cyclone: 0.42 kg/Mg or 0.83 lb/ton (inlet); 0.26 kg/Mg or 0.52 lb/ton (outlet)

- Crippen cleaner cyclone: 1.1 kg/Mg or 2.2 lb/ton (inlet); 0.045 kg/Mg or 0.090 lb/ton (outlet)

It is generally agreed that emission measurements taken at the inlet of a control device do not accurately reflect emissions from uncontrolled sources. It is agreed that the emission estimates based on control device inlet data are biased high for uncontrolled emissions at operations not equipped with aspiration systems. Therefore, the control device inlet data in this report have not been used to estimate uncontrolled emissions.

The test results found in Reference 27 were found to be well documented and generally of good quality. However, certain deficiencies were noted in respect to the lack of raw filter weights, instrument calibration records, type of grain processed, and the like. For these reasons, coupled with the fact that a nonstandard test method (i.e., ASME PTC 27) was used to derive the emission rates, a rating of C was assigned to the data in Reference 27. Applicable report excerpts and calculations are provided in Appendix I.

4.1.8 Reference 33 (1974)

Reference 33 reports source test results for an export terminal elevator in Seattle, Washington, conducted in support of New Source Performance Standards. Triplicate EPA Method 5 measurements were conducted at the inlet and outlet of baghouse dust collectors controlling emissions from boxcar unloading and ship loading systems. Wheat was the only grain handled during testing. Single particle sizing runs were also attempted at each measurement location using a Brink five-stage cascade impactor. Because of the heavy loadings, particle sizing at the inlet of the shiploader baghouse was unsuccessful, so data are not provided for this measurement location. A summary of the particle sizing data is provided in Table 4-7.

TABLE 4-7. PARTICLE SIZING RESULTS FROM REFERENCE 33[a]

Sampling location	Impactor cut-point, µmA[b]	Cumulative weight percent less than stated cut-point
Boxcar dump baghouse inlet	2.40 1.42 0.97 0.51 0.33	20.0 9.3 2.7 2.7 2.7
Boxcar dump baghouse outlet	3.23 1.91 1.31 0.69 0.45	80.0 56.0 44.0 36.0 32.0
Ship loader baghouse outlet	3.28 1.94 1.33 0.71 0.46	10.6 1.0 Nil Nil Nil

[a]From page 11 of test report.
[b]Cut-point is the characteristic particle diameter which represents the 50 percent collection efficiency of each impactor stage for a constant flow rate through the sampler. Micrometers in aerodynamic diameter (equivalent unit density spheres).

It is generally agreed that emission measurements taken at the inlet of a control device do not accurately reflect emissions from uncontrolled sources. It is agreed that the emission estimates based on control device inlet data are biased high for uncontrolled emissions at operations not equipped with aspiration systems. Therefore, the control device inlet data in this report have not been used to estimate uncontrolled emissions. In addition, the baghouse outlet data have not been used because the shiploading operations in this test are not expected to be representative of current shiploading practices.

The method used to determine particle size did not seem appropriate for control device inlet emissions testing, as reflected in the generally poor sizing results. For the above reasons, a rating of C was assigned to the particle size data contained in Reference 33. Excerpts from the test report and applicable calculations are shown in Appendix J.

4.1.9 <u>Reference 35 (1974)</u>

Reference 35 reports the results of PM source tests conducted by an EPA contractor at a large export terminal elevator located in Destrehan, Louisiana. Triplicate EPA Method 5 tests for both filterable and condensable PM were performed on the inlet and outlet of a baghouse dust collector controlling emissions from a barge unloader (marine leg) during the processing of soybeans and corn. Two particle sizing runs were also performed on the baghouse outlet using a Brink Model BMS-11 cascade impactor. (Note that the baghouse had a number of broken bags, which caused worst-case emissions to be measured at this sampling location.) Only two of the Method 5 tests at the baghouse inlet were considered valid due to nonisokinetic sampling during Run No. 1.

It is generally agreed that emission measurements taken at the inlet of a control device do not accurately reflect emissions from uncontrolled sources. It is agreed that the emission estimates based on control device inlet data are biased high for uncontrolled emissions at operations not equipped with aspiration systems. Therefore, the control device inlet data in this report have not been used to estimate uncontrolled emissions. These tests were conducted using a generally sound methodology with adequate documentation of the test methods and results. However, the outlet data are not representative of a well-operated and maintained baghouse collector. Selected pages from the test report were retained in Appendix K for reference.

4.1.10 <u>Reference 36 (1973)</u>

Reference 36 is the report of an engineering and cost study for grain and feed operations. The document contains survey information from a variety of public and private sources on emissions from grain elevators, feed mills, and grain processing plants of various types. Normally such studies are not used to develop AP-42 emission factors because no original data are provided.

For a survey-type report, the test data presented are reasonably documented with explanations provided in the text regarding the general source of the data, the test method(s) used, etc. However, the origin of many data sets is not clearly identified, nor are the data publicly accessible. Therefore, the information was used with caution in developing candidate emission factors and only in limited cases to improve the quality of the emission estimates developed. A rating of D was assigned to any data obtained from Reference 36. Applicable portions of the document, as well as calculations performed on the data, are included in Appendix L.

4.1.11 <u>Reference 37 (1973)</u>

Reference 37 reports results from a PM source test conducted by an EPA contractor at a grain and feed mill located in Portland, Oregon. Triplicate EPA Method 5 tests were conducted on the outlet of a baghouse controlling emissions from a hammermill processing a combination of oats, barley, alfalfa, and corn. Quadruplicate runs were also conducted in the study using a high volume stack sampler developed at Oregon State University but were not incorporated into the AP-42 section. The average total PM emission factors from these tests are shown below.

	Filterable PM	Total condensable PM
• EPA Method 5 sampling train:	0.011 kg/Mg (0.022 lb/ton)	0.013 kg/Mg (0.026 lb/ton)
• High volume sampling train:	0.0865 kg/Mg (0.173 lb/ton)	

The tests described in Reference 37 were found to be conducted using sound methodology and with generally adequate documentation. However, because data on an instrument calibration and tare and final filter weights were missing, the filterable PM data contained in Reference 37 were assigned a rating of B using the criteria specified in Section 3 of this report. Hammermill operations are physical processes that occur primarily at ambient conditions; under these conditions, it is difficult to understand the formation of condensable PM. At the time of this test (1973), Method 5 was a relatively new method and test conditions were not as rigorous as the current test method. Because of the uncertainty regarding the formation of condensable PM, these data were not used for emission factor development. Selected pages from the test report are provided in Appendix M.

4.1.12 Reference 38 (1972)

Reference 38 reports the results of PM source tests conducted by an EPA contractor on a pellet cooler and hammermill located at a feed mill in Louisville, Kentucky. Triplicate EPA Method 5 runs were performed at the inlet and outlet of the cooler cyclone and at the outlet of the hammermill cyclone. The composition of the feed being processed by the pellet cooler consisted of a mixture of corn, wheat, and soybean meal along with other additives. The hammermill was grinding whole kernel corn for use as a basic feed ingredient. The average filterable and total condensable PM emission factors determined during this study are shown below:

	Emission factors, kg/mg (lb/ton)	
Operation	Filterable PM	Total condensable PM
• Pellet cooler cyclone inlet:	2.7 (5.4)	0.050 (0.10)
• Pellet cooler cyclone outlet:	0.098 (0.20)	0.049 (0.098)
• Hammermill cyclone outlet:	0.060 (0.12)	0.021 (0.041)

Note that laboratory sheets indicate that most of the condensable material was contained in the back half acetone rinse.

It is generally agreed that emission measurements taken at the inlet of a control device do not accurately reflect emissions from uncontrolled sources. It is agreed that the emission estimates based on control device inlet data are biased high for uncontrolled emissions at operations not equipped with aspiration systems. Therefore, the control device inlet data in this report have not been used to estimate uncontrolled emissions. Because of the process conditions, condensable PM from the pellet cooler could be expected, but its formation during hammermill operations cannot be readily explained (Reference 37 summary). Therefore, the condensable PM data for the pellet cooler outlet have been used for emission factor development but the data for the hammermill have not been used.

The tests reported in Reference 38 were found to be conducted using sound methodology with adequate documentation provided for evaluation purposes. Therefore, a rating of A was assigned to the filterable PM and B to the pellet cooler cyclone outlet condensable PM test data found in this reference. Applicable portions of the document and associated calculations have been provided in Appendix N.

4.1.13 Reference 39 (1972)

Reference 39 reports the results from a PM source test performed by an EPA contractor on the outlet of a baghouse collector controlling emissions from a truck dump at an elevator located in Fayetteville, North Carolina. Triplicate EPA Method 5 measurements were performed in the stack used during soybean unloading. Of the three runs conducted, only two met the applicable criteria for isokinetic sampling. The results of the valid filterable PM tests are summarized below. The total condensable PM data from this test are cited below but are not used for developing emission factors. Recent emission testing of grain receiving operations do not indicate the formation of condensable PM. Considering the conditions under which grain receiving operations occur, the formation of condensable PM would not be anticipated and the date of these tests provides a degree of uncertainty concerning the test method.

- Filterable PM

- Run No. 1: $\frac{0.62 \text{ lb/hr}}{68.8 \text{ ton/hr}}$ = 0.0090 lb/ton (0.0045 kg/Mg)

- Run No. 2: $\frac{0.83 \text{ lb/hr}}{25.1 \text{ ton/hr}}$ = 0.033 lb/ton (0.017 kg/Mg)

- Total condensable PM

- Run 1: $\frac{0.24 \text{ lb/hr}}{68.8 \text{ ton/hr}}$ = 0.0034 lb/ton (0.012 kg/Mg)

- Run 2: $\frac{1.30 \text{ lb/hr}}{25.1 \text{ ton/hr}}$ = 0.052 lb/ton (0.012 kg/Mg)

- Run 3: $\frac{0.14 \text{ lb/hr}}{79 \text{ ton/hr}}$ = 0.0018 lb/ton (0.00089 kg/Mg)

The tests described in Reference 39 were found to be conducted using sound methodology and with generally adequate documentation. However, because information on instrument calibration and results of the gravimetric analyses were missing and the results from the two filterable PM tests differ by more than a factor of three, the data contained in Reference 39 for filterable PM were assigned a rating of B. Selected pages from the test report as well as calculations of the average emission rate are provided in Appendix O.

4.1.14 Reference 40 (1972)

Reference 40 presents the results of PM compliance tests conducted on two grain cleaners and the headhouse of a country elevator located in Minot, North Dakota. Duplicate measurements were made using ASME PTC 27 at the inlet and outlet of two cyclone collectors controlling emissions from (1) the combined effluent from two grain cleaners, and (2) the headhouse dust control system. The headhouse system was equipped with pick-up points at the following locations: three legs and distributor heads; front, back, and annex dump pits; two screw conveyors; scale hopper; and floor sweeps (not in operation during testing). The average total PM emission factor at each measurement point was:

- Grain cleaner cyclone inlet: $\frac{15.68 \text{ lb/hr}}{36.87 \text{ ton/hr}}$ = 0.43 lb/ton (0.21 kg/Mg)

- Grain cleaner cyclone outlet: $\frac{2.56 \text{ lb/hr}}{36.87 \text{ ton/hr}}$ = 0.069 lb/ton (0.035 kg/Mg)

- House system cyclone inlet: $\frac{81.21 \text{ lb/hr}}{167.50 \text{ ton/hr}}$ = 0.48 lb/ton (0.24 kg/Mg)

- House system cyclone outlet: $\frac{13.65 \text{ lb/hr}}{167.50 \text{ ton/hr}}$ = 0.081 lb/ton (0.041 kg/Mg)

It is generally agreed that emission measurements taken at the inlet of a control device do not accurately reflect emissions from uncontrolled sources. It is agreed that the emission estimates based on control device inlet data are biased high for uncontrolled emissions at operations not equipped with aspiration systems. Therefore, the control device inlet data in this report have not been used to estimate uncontrolled emissions.

The tests described in Reference 40 were found to be conducted using nonstandard methodology but with generally adequate documentation. However some data on instrument calibration, results of the gravimetric analyses, and type of grain processed were also missing. Consequently, the data contained in Reference 40 were assigned a rating of C. Selected pages from the test report are provided in Appendix P.

4.1.15 Reference 41 (1972)

Reference 41 reports the results of filterable and condensable PM source tests conducted by an EPA contractor on a hammermill and two pellet coolers at a feed and grain mill located in Sioux City, Iowa. Triplicate EPA Method 5 measurements were performed at five locations: hammermill cyclone outlet; column cooler cyclone inlet and outlet; and pan cooler cyclone inlet and outlet. During these tests, yellow corn was processed through the hammermill, and mixed feed pellets were processed through the two coolers. The report did indicate that the process varied somewhat during the three runs on the pan cooler. For the first two runs, calcium carbonate was added to the grain stream upstream from the cooler at the rate of 26 lb/ton of grain and 28 lb/ton of grain, respectively. No calcium carbonate was added on the third run. Subsequent conversations with industry personnel indicated that this practice is abnormal. Although calcium carbonate is added to some feeds, the universal practice is to add it as the feed is transferred to the bin downstream from the cooler. Consequently, Runs 1 and 2 are not considered to constitute standard practice. Average emission factors calculated from the test results are shown below.

Source	Filterable PM kg/Mg (lb/ton)	Condensable PM kg/Mg (lb/ton)
Hammermill cyclone outlet	0.0050 (0.010)	0.0022 (0.0044)
Column cooler cyclone inlet	20.8 (41.7)	0.0084 (0.017)
Column cooler cyclone outlet	0.018 (0.037)	0.014 (0.028)
Pan cooler cyclone inlet (with dusting)	14.6 (29.2)	0.0049 (0.0098)
Pan cooler cyclone inlet (without dusting)	13.5 (26.9)	0.0061 (0.012)
Pan cooler cyclone outlet (with dusting)	1.39 (2.78)	0.051 (0.102)
Pan cooler cyclone outlet (without dusting)	0.518 (1.04)	0.022 (0.044)

It is generally agreed that emission measurements taken at the inlet of a control device do not accurately reflect emissions from uncontrolled sources. It is agreed that the emission estimates based on control device inlet data are biased high for uncontrolled emissions at operations not equipped with aspiration systems. Therefore, the control device inlet data in this report have not been used to estimate uncontrolled emissions. The pan cooler data were considered to be unratable because only one run was conducted under operating conditions considered to be normal by industry standards. Pan cooler data were not used to develop emission estimates. The only remaining data are the outlet data for the hammermill and the column cooler. For reasons cited earlier in this section, data for condensable PM from tests on hammermills are not used to develop emission factors. For the column cooler, the high ratio of the condensable PM emissions data to the filterable PM data is inconsistent with more recent emission test data for cooling feed pellets; therefore, the column cooler data are not used to estimate emissions.

The tests described in Reference 41 were found to be conducted using methodology that involved a slight modification of EPA Method 5, but the report had adequate documentation, and the modifications will have minimal impact on results. Also, instrument calibration and laboratory analyses data were missing. Therefore, the data contained in this reference for the hammermill and column cooler were assigned a rating of B. Selected pages from the test report as well as applicable calculations are provided in Appendix Q.

4.1.16 Reference 42 (1972)

Reference 42 summarizes the results of PM compliance tests performed at two North Dakota country elevators. Duplicate tests were conducted using ASME PTC 27 procedures at the inlet and outlet of cyclone dust collectors serving a grain cleaner and a house dust control system during spring wheat processing. The house dust control system comprised the front and back dump pit, elevator legs, and distributor head. Average results calculated from the data collected during the testing program are summarized below.

- Carter cleaner cyclone inlet: 0.092 kg/Mg (0.18 lb/ton)
- Carter cleaner cyclone outlet: 0.049 kg/Mg (0.097 lb/ton)
- House system cyclone inlet: 0.068 kg/Mg (0.14 lb/ton)
- House system cyclone outlet: 0.0046 kg/Mg (0.0092 lb/ton)

It is generally agreed that emission measurements taken at the inlet of a control device do not accurately reflect emissions from uncontrolled sources. It is agreed that the emission estimates based on control device inlet data are biased high for uncontrolled emissions at operations not equipped with aspiration systems. Therefore, the control device inlet data in this report have not been used to estimate uncontrolled emissions.

The tests described in Reference 42 were found to be properly conducted and adequately documented. However, because a nonstandard test method was used and instrument calibration and laboratory analyses data were missing, the data contained in this reference were assigned a rating of C. Selected pages from the test report as well as applicable calculations are provided in Appendix R.

4.1.17 Reference 43 (1972)

Reference 43 is the report of a PM compliance test conducted at an elevator located in Curren, Illinois. Duplicate measurements were conducted using ASME PTC 27 at the outlet of three cyclone collectors serving one unspecified source and a railcar loading operation. A Rader high volume stack sampler was used. The average emission factor for the railcar loading tests were determined as follows:

Average emission factor: $\frac{0.06 \text{ lb/hr}}{29.6 \text{ ton/hr}} = 0.002 \ \frac{\text{lb}}{\text{ton}}$ or $0.001 \ \frac{\text{kg}}{\text{Mg}}$

The test protocol, data, and results were incompletely documented and a nonstandard method (ASME PTC 27) was used to conduct the tests. For these reasons, a rating of D was assigned to the test data in Reference 43. Application portions of the report are reproduced in Appendix S.

4.1.18 Reference 46 (1982)

Reference 46 presents the results of a research study designed to assess the effects of water and oil suppression in reducing dust generation from grain handling. The tests were conducted in a controlled situation in an Ohio elevator by transferring grain from one storage bin to another. No actual emission rate measurements were taken as a part of the study, but dust concentration measurements were made at several different points in the process under different operating conditions. Because only concentration measurements were obtained, the data are not sufficient to develop emission factors. However, the concentration measures may provide some indication of the emission reduction potential of water and oil suppression. Because data on these techniques are scarce, information from Reference 46 that describes the test program and performance results is summarized below.

An assessment of the effect of water and oil suppression on dust reduction was obtained by applying oil to grain being transferred from one storage bin to another. Grain was moved from the first storage bin on a 36-inch wide enclosed conveyor belt running at 400 ft/min. At site A, the first belt transferred grain onto a second similar belt, from where the grain was moved 100 feet to site B, the end of the second belt. Dust suppressant was added to both sides of the falling grain stream at site A. Grain was discharged from the belt at Site B into 25 feet of spouting where it fell by gravity, entered the boot on the descending side of the bucket elevator, was elevated to the top of the leg, and discharged through spouting into a 2,500-bushel garner and then into a 2,500-bushel scale. From the scale, the grain entered a distributor that directed the flow to site C, the beginning of the gallery belt. The vertical distance of the fall of grain from the head of the leg to the gallery belt was 100 feet. Grain was then moved 85 feet from site C to site D, the location of the first tripper, where it was transferred to the house belt. The time required for grain to move from Site A to sites B, C, and D was 15, 50, and 50 seconds, respectively. Grain was continuously moved on the house belt to site E, the location of the second tripper, which was stationed at the entrance to one of three similar test bins. Each test bin was 114 feet deep and had a capacity of 9,000 bushels. Distances from site D to the three bin sites were 25, 310, and 320 feet. Total lapsed times for grain to move from site A to each of the three bin sites were 40, 70, and 71 seconds, respectively.

The grain elevator was equipped with several dust control ventilation systems with fabric filters. The collected dust was discharged through ducts into a dust bin. The lower system collected dust through ducts located at the end of the second enclosed belt (site B) and in the boot of the bucket elevator. The upper system collected dust from the head of the bucket elevator and the garner site. The dust control system for the gallery collected dust from hoods over the beginning of the gallery belt and the first tripper (sites C and D). The system in the headhouse collected dust from the hoods over the beginning of the house belt and second tripper (site D).

Hi-Vol air samplers operating at a rate of 60 cfm were used to collect dust samples at three locations during the test. The first location was inside the conveyor enclosure at Site B. The sampler was located about 18 in. above the grain surface and 4 ft from the nearest exhaust duct for the dust control system. The second location was in the gallery area near the tripper belt located downstream from the scale (Site C). The sampler was installed in an open area about 3 ft from the belt and about 6 ft downstream from where the grain was discharged onto the belt. The third site was inside the storage bin being filled. The Hi-Vol was suspended about 18 in. from the top of the bin during the time that the grain was being deposited to the bin.

The resultant dust concentration measurements are summarized in Table 4-8. Again, these data are insufficient to develop emission factors, so the data are not rated. However, the methods used to collect the samples appear to be reasonable and the test results were well documented in Reference 46. Consequently, these data may provide some indication of the emission reduction potential of mineral oil and soybean oil suppression systems.

4.1.19 Reference 47 (1992)

Reference 47 reports the results of tests to determine PM emission rates and particle size distributions from the milling process and ambient concentrations of particulates in the vicinity of loading and receiving areas during loading/unloading operations at the Pacific International Rice Mills, Inc. (PIRMI), facility in Woodland, California. The dust collection system utilizes baghouse filters on all collection units, and in the case of bran filters, a cyclone separator upstream of the baghouse. A single test was performed for each of the four dust collectors that service different segments of the process area. Tests for PM emission rates were performed using EPA Method 5 and for particle sizing using CARB Method 5. Equipment was calibrated according to EPA methodology from EPA 600/4-77-0278. A single test of ambient particulate concentration was performed at each of four different loading/unloading operations using two or three high volume air samplers placed at strategic locations. Results of the process area testing were reported in grains per standard dry cubic feet (concentration), and in pounds per hour (emission rate). Emission rates were given for the front half (filterable PM) and back half (condensable PM), as well as the percent of filterable PM-10 in the total filterable PM. A breakdown of condensable PM emissions between organic and inorganic PM was not provided. Results of ambient air testing of loading/unloading areas were reported as concentrations only. The test data are presented in Table 4-9.

The total condensable PM data from this test are cited in Table 4-9 but are not used for developing emission factors. Recent emission testing of grain receiving operations do not indicate the formation of condensable PM. Considering the conditions under which grain receiving operations occur, the formation of condensable PM would not be anticipated.

Test procedures were well-documented in this report. Raw data and calculation examples were given for calibrations as well as samples. However, only one test run was performed for each dust collector. In addition, some down time occurred during test runs for two of the dust collectors. Finally,

TABLE 4-8. DUST CONCENTRATION ASSOCIATED WITH DUST SUPPRESSION TESTS FROM REFERENCE 46

Grain	APCD status	Control level[a]	Dust readings (g/m^3)		
			Gallery (C)	Enclosed belt (B)	Bin (E)
Corn	On	None	0.01	0.86	3.0
	Off	None	1.3	17	3.2
	On	0.17% H_2O	0.01	NA	2.0
	On	0.18% H_2O	0.006	0.51	2.7
	On	0.3% H_2O	0.017	0.41	2.4
	Off	0.18% H_2O	0.21	14	1.9
	Off	0.3% H_2O	0.26	3.4	1.9
	Off	0.33% H_2O	0.12	6.5	2.0
	On	0.03% SO	0.004	0.71	0.90
	On	0.06% SO	0.006	0.66	0.58
	On	0.10% SO	0.003	0.75	0.92
	Off	0.03% SO	0.082	9.9	0.71
	Off	0.06% SO	0.060	3.5	0.58
	Off	0.10% SO	0.075		0.84
	On	0.02% MO	0.002	0.59	0.68
	Off	0.02% MO	0.043	7.5	0.98
	Off	0.049% MO	0.056	6.4	0.43
	Off	0.08% MO	0.024	7.4	0.39
Wheat	On	None	0.007	0.37	2.2
	Off	None	0.10	5.5	1.8
	Off	0.02% SO	0.36	8.0	1.2
	On	0.03% SO	0.005	0.29	1.1
	On	0.03% SO	0.032	3.2	0.28
	Off	0.06% SO	0.032	2.8	0.23
Soybeans	On	None	0.017	1.1	5.6
	Off	None	1.1	7.9	4.3
	On	0.03% SO	0.005	0.27	0.66
	Off	0.03% SO	0.062	5.2	0.95
	Off	0.06% SO	0.079	5.9	0.47

[a]H_2O = Water, SO = Soybean oil, MO = Mineral oil.

TABLE 4-9. PARTICULATE EMISSIONS FROM A RICE MILLING OPERATION
REFERENCE 47

DATA QUALITY RATING: D

Emission	Process Area			
	Paddy rice cleaners	General mill house	Shelled rice aspirator	Bran from mill and pearlers
Process rate, kg/hr (lb/hr) rough rice processed	27,760 (61,200)	15,513 (34,200)	28,803 (63,500)	17,236 (38,000)
Concentration (grains/dscf)				
Total:	0.0015	0.0200	0.0046	0.0023
Filterable (total):	0.0009	0.0184	0.0019	0.0013
Filterable PM-10:	0.0007	0.0068	0.0016	0.0008
Condensable (total):	0.0006	0.0016	0.0027	0.0010
Emission rate, kg/hr (lb/hr)				
Total:	0.0721 (0.1590)	2.3174 (5.1090)	0.1048 (0.2310)	0.2522 (0.5560)
Filterable (total):	0.0435 (0.0960)	2.1319 (4.7000)	0.0435 (0.0960)	0.1429 (0.3150)
Filterable PM-10:	0.0359 (0.0792)	0.7937 (1.7484)	0.0371 (0.0819)	0.0889 (0.1959)
Condensable (total):	0.0286 (0.0630)	0.1855 (0.4090)	0.0612 (0.1350)	0.1093 (0.2410)
Emission factor, kg/Mg (lb/ton) rough rice processed				
Total:	0.0026 (0.0052)	0.15 (0.30)	0.0036 (0.0073)	0.015 (0.029)
Filterable (total):	0.0016 (0.0031)	0.14 (0.27)	0.0015 (0.0030)	0.0083 (0.017)
Filterable PM-10:	0.0013 (0.0026)	0.051 (0.10)	0.0013 (0.0026)	0.0052 (0.010)
Condensable (total):	0.0010 (0.0021)	0.012 (0.024)	0.0021 (0.0043)	0.0063 (0.013)

process rates varied considerably among the tests of the four dust collectors. Therefore, these data were assigned a rating of D. Pertinent excerpts of the test report are included in Appendix T.

4.1.20 Reference 48 (1993)

Reference 48 is a letter submitted in response to a draft version of Section 9.9.1 that contains as attachments excerpts from test reports on five rice dryers conducted in 1980 and 1981 in Butte County, CA. These excerpts provide very limited data on either the process or test method. For each facility, the type of dryer is identified, the process rate is given in a summary table, and a schematic of the test train is provided; no other information on process operations or test methods is presented. Based on the structure of the test train, the two-run tests appear to have been conducted using a Hi Vol method, but documentation is lacking. However, full traverses do not appear to have been conducted on all tests, and the methods used to determine volumetric flows cannot be determined.

Typically data with such sparse documentation would not be used to develop AP-42 emission factors. However, because no other reliable data are available for rice drying operations, these data were retained and rated D. The data from these tests are summarized in Table 4-10, and the test report excerpts are presented in Appendix U.

TABLE 4-10. SUMMARY OF RICE DRYER EMISSION FACTORS FROM REFERENCE 48

Location	Dryer type	Filterable PM emission factor kg/Mg	lb/ton
BCRG-Richrale	Gas-fired screen	0.034	0.068
BCRG-Richale	Screen-baffle	0.082	0.16
BCRG-Riceton	Gas-fired screen	0.027	0.054
Red top	Gas-fired screen	0.057	0.11
RGA	Vertical screen	0.082	0.16

4.1.21 Reference 49 (1974)

Reference 49 summarizes a study of rice dryer emissions conducted by the California Air Resources Board in the Sacramento Basin in 1972 and 1973. Tests were conducted on 15 screen dryers, 9 baffle dryers, and 1 LSU aeration dryer. Two runs were conducted on each dryer using a Hi-Vol sampler; the report did not specify the location of the tests, whether the exhaust stream was traversed, whether isokinetic sampling was used, and how volumetric flows were determined. Limited particle size data also were obtained with an eight-stage Andersen cascade impactor, but the method appears to have been nonstandard. The report contained no process information for any of the dryers tested.

Information obtained as a part of this AP-42 revision indicates that rice properties have changed substantially over the past 20 years, and that these changes have had a significant impact on the emission potential of rice dryers.[50] Consequently, the data in Reference 49 are considered unratable for purposes of AP-42 emission factor development. However, because the data do provide some indication of the relative emissions from different types of dryers and controls, they are summarized in Table 4-11. Excerpts from

TABLE 4-11. SUMMARY OF EMISSION FACTORS FROM CARB RICE DRYER TESTS REFERENCE 49

Dryer	Dryer type	Control	Filterable PM emission factor	
			kg/Mg	lb/ton
A	Screen	None	0.20	0.40
B	Screen	None	0.38	0.77
C	Screen	None	0.85	1.7
D	Screen	None	0.38	0.76
E	Screen	None	0.05	0.10
F	Screen	None	0.21	0.42
G	Screen	None	0.45	0.90
H	Screen	None	0.90	1.8
I	Screen	None	0.60	1.2
J	Screen	Widenmann50 mesh screen	0.68	1.4
K	Screen	CamVac	0.072	0.14
L	Baffle	None	0.96	1.9
M	Baffle	None	0.66	1.3
N	Baffle	None	1.3	2.6
O	Baffle	None	1.3	2.6
P	Baffle	None	0.35	0.70
Q	Baffle	None	0.26	0.52
R	Baffle	None	0.75	1.5
S	Baffle	None	0.60	1.2
T	LSU aeration	None	0.65	1.3
U	Baffle	CamVac with 80 mesh screen	0.15	0.30

the report that contain data summaries for both the filterable PM results and the particle size results are included in Appendix V.

4.1.22 Reference 53 (1983)

Reference 53 is the report of PM compliance tests conducted at the outlet of cyclone dust collectors controlling emissions from a rolled grain system and two pellet coolers at a feed mill located in California. Triplicate measurements were conducted for each process using EPA Method 5 for both filterable and condensable PM, with the results provided in terms of pounds of PM per hour. Production rates in terms of tons per hour were provided, such that emission factors in units of pounds of PM per ton of material processed could be calculated. The average filterable and total condensable PM emission factors determined from the test results are summarized as follows:

		Emission factor, kg/Mg (lb/ton)	
Source	Grain	Filterable PM	Total condensable PM
Roller mill cyclone outlet	Corn (2 runs)	0.10 (0.20)	0.05 (0.10)
	Barley (1 run)	0.021 (0.042)	0.026 (0.051)
	All (3 runs)	0.075 (0.15)	0.043 (0.085)
Pellet cooler No. 1 cyclone outlet	Poultry feed	0.055 (0.11)	0.0085 (0.017)
Pellet cooler No. 2 cyclone outlet	Dairy feed	0.09 (0.18)	0.031 (0.061)

Total condensable PM emissions data from pellet coolers have been observed in other source tests and used to develop emission estimates. Because of the moisture content of the pellets and the initial elevated temperature of the pellets, condensable PM emissions would be anticipated. However, condensable PM emissions from the grain roller mill would not be anticipated and are difficult to rationalize. The filterable PM data and the condensable PM data for the pellet coolers shown above are used to develop emission factors; the condensable PM data for the roller mill are not used.

The information contained in Reference 53 was poorly documented with no raw data, calculations, calibration data, etc. Based on these limitations, a rating of C was assigned to the emissions data contained in Reference 53. Applicable portions of the test report are provided in Appendix W.

4.1.23 Reference 54 (1992)

Reference 54 is the report of PM compliance tests conducted on a pellet cooler and hammermill located at a feed mill in Mississippi. Triplicate EPA Method 5 runs were performed at the outlet of the cooler triple cyclone and at the outlet of the hammermill fabric filter. Filterable PM results were reported in terms of pounds of PM per hour. Process rates for the tests were provided in a supplemental letter to EPA (Reference 55) such that emission factors in units of pounds of PM per ton of material processed could be calculated. The average filterable PM emission factors determined from the test results are summarized as follows:

Source	Filterable PM kg/Mg (lb/ton)
Hammermill fabric filter outlet	0.0014 (0.0028)
Pellet cooler triple cyclone outlet	0.075 (0.15)

The tests described in Reference 54 were found to be conducted using sound methodology and with generally adequate documentation for evaluation purposes. Therefore, a rating of B was assigned to the filterable PM test data found in this reference. Applicable portions of the document and associated calculations have been provided in Appendix X.

4.1.24 Reference 56 (1994)

Reference 56 is the report of PM compliance tests conducted at the same facility as described above in Reference 54 on a pellet cooler and hammermill located at a feed mill in Mississippi. Triplicate EPA Method 5 runs were performed at the outlet of the cooler triple cyclone and at the outlet of the hammermill fabric filter. Filterable PM results were reported in terms of pounds of PM per hour. Process rates for the tests were provided in a supplemental letter to EPA (Reference 55) such that emission factors in units of pounds of PM per ton of material processed could be calculated. The average filterable PM emission factors determined from the test results are summarized as follows:

Source	Filterable PM kg/Mg (lb/ton)
Hammermill fabric filter outlet	0.00065 (0.0013)
Pellet cooler triple cyclone outlet	0.050 (0.10)

The tests described in Reference 56 were found to be conducted using methodology that involved a slight modification of EPA Method 5, but the report had adequate documentation, and the modifications will have minimal impact on results. Therefore, a rating of B was assigned to the filterable PM test data found in this reference. Applicable portions of the document and associated calculations have been provided in Appendix Y.

4.1.25 Reference 57 (1994)

Reference 57 presents the results of a scoping field study performed at a grain elevator in Nebraska. The study addressed total PM and PM-10 emissions generated by transferring grain onto a gallery belt. A major objective of the study was to develop quantitative information on the effectiveness of mineral oil suppression. The study considered two grains, milo and corn; tests of controlled and uncontrolled emissions for each grain were performed. An exposure profiling technique was used for the tests in this study. This technique used a mass-balance calculation method similar to EPA Method 5 stack testing, rather than a generalized atmospheric dispersion model.

The average uncontrolled and controlled PM-10 and total PM emission factors determined from the test results are summarized as follows:

Grain	Control	Emission factor, kg/Mg (lb/ton)	
		PM-10	Total PM
Milo	Uncontrolled	0.0011 (0.0021)	0.0039 (0.0078)
	Oil (25 psi)	0.00038 (0.00076)	0.0016 (0.0032)
	Oil (20 psi)	0.0006 (0.0012)	0.0031 (0.0062)
Corn	Uncontrolled	0.0012 (0.0023)	0.0047 (0.0093)
	Oil (25 psi)	0.00036 (0.00071)	0.0025 (0.0049)
	Oil (20 psi)	0.00024 (0.00048)	0.0020 (0.0040)

The Nebraska country elevator applies food grade mineral oil through a system that sprays oil through inspection ports on the elevator legs. The spray system contains a check valve and cannot operate with the oil pressure less than 20 psi. The system typically operates at 25 psi. The spray tip used delivers 0.076 gal/min at 80°F and 20 psi, and 0.1 gal/min at 80°F and 40 psi. The mineral oil suppression system, as typically operated (i.e., at 25 psi) yielded an average PM-10 and total PM control efficiency of approximately 60 percent. The test data from this reference were assigned a rating of B. Applicable portions of the document and associated calculations have been provided in Appendix Z.

It should be noted that the mineral oil control efficiency values obtained during this scoping study may be lower than that which can be achieved at other installations. This is due to the fact that this elevator applies the oil to grain in the leg. As a result, not all of the oil adheres to the grain and only a limited amount of mixing can occur before the grain hits the gallery belt. Other installations designed to spray oil during active grain tumbling are expected to exhibit higher control efficiency.

4.1.26 Reference 58 (1994)

Reference 58 presents the results of a grain elevator dust emission study conducted in September 1994 by Oklahoma State University in conjunction with Oklahoma DEQ and the Oklahoma Grain and Feed Association Task Force. The objectives of the study were to develop PM emission factors for grain receiving and shipping, and to measure the effects of dump pit baffles and truck type on receiving emissions. Hard red winter wheat was the only grain considered in the study. Receiving emissions were measured for straight trucks and hopper bottom trucks. The baffle efficiency tests included only straight trucks.

The basic design of the emission tests was to perform typical receiving and loading operations in a totally enclosed dump shed and to evacuate all of the air in the shed through filter bags, capturing the airborne dust particles. The suction system used to capture grain dust was engineered to capture emitted grain dust while not artificially separating fine particles from the grain. Two high-volume propeller fans were used to keep all airborne dust in suspension until it could be evacuated through the filter bags.

After each test, the dust which settled to the dump shed floor was swept up and weighed. One open door test during unloading of a straight truck was conducted to determine the amount of floor dust which would be expected during normal operations. To compensate for testing with the shed doors closed (instead of open as is typical), the difference between the two floor dust weights was added to the emission measurements as an adjustment to the airborne dust emissions.

The baffle efficiency tests showed the control efficiency for the baffles at this facility to be approximately 21 percent. The dump pit baffle design used in this test was installed around 1990.

The average uncontrolled total PM emission factors determined from the test results are summarized below.

	Total PM	
Process	Range, kg/Mg (lb/ton)	Average, kg/Mg (lb/ton)
Grain receiving, straight truck	0.028-0.041 (0.0553-0.081)	0.034 (0.067)
Grain receiving, hopper truck	0.018-0.021 (0.0363-0.041)	0.019 (0.038)
Grain shipping, truck	0.0037-0.0073 (0.0074-0.0145)	0.0055 (0.011)

The tests described in Reference 58 were found to be properly conducted and adequately documented. The data contained in this reference were assigned a rating of B. Selected pages from the test report as well as applicable calculations are provided in Appendix AA.

4.1.27 Reference 60 (1996)

Reference 60 describes the results of a field testing program conducted for the National Cattleman's Beef Association. Testing was performed at three feed mills located in Kansas, Nebraska, and Texas. Data were gathered for total PM and PM-10 emissions from grain unloading and feed loading operations at feed mills. The grain receiving tests considered three grains: corn, wheat, and milo.

Two sampling protocols were used to obtain measurements of TSP emission rates resulting from grain receiving and feed shipping operations. The first protocol used a plastic enclosure under the truck (for grain receiving) or over the truck (for feed loading) to contain the dust entrained in the air. The enclosure prevented the dust from moving out of the shed with the ambient air and facilitated the capture of dust with four high volume samplers. Laboratory test results indicated that a portion of the dust captured could have been deposited inside the preseparator cyclone and associated duct prior to the filter. In addition, grid sampling runs conducted concurrently with two "under the truck" tests indicated that approximately 30 percent of the mass of dust captured by the "under the truck" sampling protocol had escaped. As a result, all emission factors calculated using the "under the truck" protocol were increased by 35 percent (5 percent to account for dust deposition inside the preseparator plus 30 percent to account for dust escaping the plastic enclosure. The emission factors using the "over the truck" protocol were increased by 40 percent (10 percent to account for dust deposition inside the preseparator plus 30 percent to account for dust escaping the plastic enclosure).

The second protocol, referred to as grid sampling, involved measuring the concentration of PM at three different heights at the downwind exit of the shed. The particulate mass emission rate consisted of measuring the net average concentration at the downwind exit of the shed and multiplying this number by the average volumetric flow rate of air through the shed during the unloading (grain) and loading (feed) periods.

Particle size distributions were performed on the exposed filters and the dust collected in zip lock bags using the Coulter Counter Multisizer. The results suggest that the PM-10 emission factor for grain unloading should be estimated by using 15 percent of the TSP emission factor and the PM-10 emission factor for feed loading should be estimated by using 35 percent of the TSP emission factor.

The average uncontrolled PM-10 and total PM emission factors determined from the test results are summarized below.

	PM-10		Total PM	
Process	Range, kg/Mg (lb/ton)	Average, kg/Mg (lb/ton)	Range kg/Mg (lb/ton)	Average kg/Mg (lb/ton)
Grain receiving, hopper truck	0.0002-0.0054 (0.0004-0.0107)	0.0013 (0.0025)	0.0014-0.036 (0.0027-0.0711)	0.0083 (0.0166)
Feed shipping, truck	0.00005-0.0013 (0.0001-0.0026)	0.0004 (0.0008)	0.00015-0.0038 (0.0003-0.0075)	0.0017 (0.0033)

The tests described in Reference 60 were found to be properly conducted and adequately documented. The data contained in this reference were assigned a rating of B. Selected pages from the test report as well as applicable calculations are provided in Appendix BB.

4.1.28 Reference 61 (1997)

Reference 61 describes the results of a field testing program conducted for the National Grain and Feed Foundation (NGFF). Testing was performed at one country elevator and two terminal elevators. The elevators handled wheat, corn, soybeans, and sorghum. Data were gathered for dust emissions from the grain elevator building and from loading and unloading of trucks and railcars. Tests focused on PM-10 emissions. Additional testing was performed to measure the ability of vegetable and food-grade mineral oil to control dust emissions from grain handling operations. Finally, three tests were conducted to determine the PM control efficiency of dust aspiration systems.

A total of 54 tests were performed using an EPA-recommended testing technique called exposure profiling. Exposure profiling requires simultaneous multipoint sampling over the effective cross-section of the dust source plume. The method relies on a mass balance scheme similar to EPA Reference methods to test conventional ducted sources. EPA recommended this sampling technique as a more accurate method of developing uncontrolled emission factors than relying on dust concentrations at the inlet of control devices.

Dust was sampled through a cyclone preseparator which exhibits a 50 percent cutpoint of approximately 10 microns in aerodynamic diameter (μmA) when operated at 40 cfm. Thus, the cyclone collected a sample associated with PM-10 on an 8-in. by 10-in. glass fiber filter. In addition, a coarser particulate sample was collected within the body of the cyclone.

Testing showed that, for a given handling operation, there is little difference in the amount of dust between different grains. Thus, the data support combining grains into a single emission factor for a specific grain handling operation. The average uncontrolled PM-10 and total PM emission factors determined from the test results are summarized as follows:

	PM-10		Total PM	
Process	Range, kg/Mg (lb/ton)	Average, kg/Mg (lb/ton)	Range, kg/Mg (lb/ton)	Average, kg/Mg (lb/ton)
Grain receiving, straight truck	0.0065-0.057 (0.013-0.113)	0.030 (0.059)	0.077-0.25 (0.153-0.497)	0.15 (0.30)
Grain receiving, hopper truck	0.0015-0.0052 (0.0029-0.0103)	0.0039 (0.0078)	0.0034-0.040 (0.0067-0.079)	0.016 (0.032)
Grain receiving, railcar	0.0015-0.0052 (0.0029-0.0103)	0.0039 (0.0078)	0.0034-0.040 (0.0067-0.079)	0.016 (0.032)
Grain shipping, truck	0.0011-0.040 (0.0021-0.079)	0.015 (0.029)	0.0049-0.18 (0.0097-0.359)	0.080 (0.16)
Grain shipping, railcar	0.00065-0.0019 (0.0013-0.0038)	0.0011 (0.0022)	0.0095-0.017 (0.019-0.034)	0.014 (0.027)
Internal handling	0.009-0.041 (0.018-0.082)	0.017 (0.034)	0.013-0.082 (0.025-0.163)	0.031 (0.061)

The oil suppression tests conducted at a country elevator and a terminal elevator suggest that, when properly applied, oil addition systems can achieve PM control efficiencies between 60 and 80 percent. The two tests conducted on a headhouse dust aspiration system at a country elevator showed a PM emission reduction of approximately 60 percent. The single test conducted on a dust aspiration system at a terminal elevator railcar loading facility indicated a PM emission reduction of 77 percent.

The tests described in Reference 61 were found to be properly conducted and adequately documented. The data contained in this reference were assigned a rating of B. Selected pages from the test report as well as applicable calculations are provided in Appendix CC.

4.1.29 Reference 67 (1995)

This test report documents an emission test conducted at Ladish Malting Company in Jefferson Junction, WI, on November 14, 1995. The test included six EPA Method 18 test runs (on each of five separate kiln stacks) to quantify methane and nonmethane organic compounds (NMOC) from the No. 15 Malt Kiln. A malt production rate was provided for the kiln cycle.

The No. 15 Kiln is an indirect-, natural gas-fired kiln. Heat is provided by propylene glycol-filled coils that are heated with natural gas. Barley, with about a 45 percent moisture content, enters the upper deck of the kiln and is dried, over a 24-hour period, to between 15 and 20 percent. The barley is then transferred to the lower deck of the kiln, where it is dried to about 4 percent over a second 24-hour period. At times during the cycle, sulfur is burned into the kiln. To convert from bushels produced to lb of malt produced, a factor of 40 lb/bushel was provided in a memo attached to the report. The memo, a March 27, 1996 memo to the file from J. Crawford, is a review of the test report performed by the State of Wisconsin Department of Natural Resources.

Several problems were found with the emission rate calculations in the report and the attached memo. To calculate emission rates, the flow rates (dscfm) from each of the five stacks were summed, the concentrations (ppm) from each of the five stacks were summed, and the sums were used to calculate the methane and NMOC emission rates for each test run. To correctly calculate these emission rates, the average concentration should have been used instead of the sum of the concentrations. The emission rates presented in both the report and the attached memorandum appear to be five times too high. Also, the report indicates that NMOC were not detected during any test run. The detection limit was used as an upper limit for NMOC emissions. This type of data typically is not presented in AP-42.

The attached memo provides a brief review of the report, a description of the process, a discussion of results, and a methodology for calculating emission factors from the data. The emission factor methodology provides the following information:

1. Four of the test runs (Runs 1, 2, 3, and 6) were conducted during "holding heat" conditions, which are present for 17 hours of a 24 hour kiln cycle;

2. The other 2 test runs (Runs 4 and 5) were conducted during "high heat" conditions, which are present for 5 hours of a 24 hour kiln cycle; and

3. 14,000 bushels of malt are produced during a 24 hour kiln cycle.

Item number (3) above appears to be incorrect. In Appendix E, the test report states that 7,000 bushels were on each level of the kiln during testing, but that the barley remains on each of the 2 levels for 24 hours. Therefore, for use in AP-42, a process rate of 7,000 bushels per 24 hours was used. Also, it was assumed that the kiln is not heated for two hours of the cycle, and that there are no emissions during the periods when the kiln is not heated.

Using the data from this report, an emission factor of 1.41 lb/1,000 bushels was developed for methane emissions from malt kilns. The methane data are assigned an A rating. The barley density (40 lb/bu) can be used to convert the emission factor to 0.071 lb/ton. The test methodology was sound, no problems were reported, and sufficient details about the testing and the process are provided in the report. The NMOC data are not rated for use in emission factor development because NMOC was not detected during any test run.

4.1.30 <u>Reference 68 (1991)</u>

This test report documents emission tests conducted at Busch Agricultural Resources, Inc. in Idaho Falls, Idaho on October 1, 2, and 3-6, 1991. The tests included three EPA Method 1-5 and Method 9 runs on each of two Dust Collectors (denoted 100 and 200) that control PM emissions from barley unloading operations. Also, three EPA Method 1-5 test runs and one Method 9 test run were conducted on Malt Kiln # 2. These tests were performed in order to evaluate the total particulate and visual emissions to satisfy permitting requirements for new construction. Production rates and test results were provided in the report. Raw data were not included in the report for the Method 1-5 test runs and the tabulated stack test data are incomplete.

The facility receives barley by railcar or truck. A screw conveyor transports barley to the storage silos where PM emissions from the unloading operations are controlled by dust collection systems that include reverse jet baghouses. During the tests on dust collection systems 100 and 200, an average of 7,085 and 5,777 bushels/hour of barley was unloaded, respectively. Upon cleaning and grading, grain is fed to a malt kiln to be dried. No air cleaning system is employed by Malt Kiln # 2. Malt Kiln No. 2 is an indirect-, natural gas-fired heater that processes an average of 9,400 bushels/day. Malt Kiln No. 2 was tested while processing approximately 9,400 bushels/day. Exhaust from the heaters and the drying process enters a common plenum and then exits the building through the kiln exhaust stack.

Using the data from this report, emission factors, in units of lb/ton of malted barley produced, were developed for filterable particulate emissions from fabric filter-controlled barley unloading and a malt kiln. The data are assigned a C rating. The test methodology appeared to be sound, however the test data presented in the report are incomplete. Sample Number R-8 (Malt Kiln No. 2) did not satisfy the Method 5 isokinetic requirements (88.4 percent). Selected pages from the test report as well as applicable calculations are provided in Appendix DD.

4.1.31 Reference 69 (1996)

This test report documents an emission test conducted at Busch Agricultural Resources, Inc. in Manitowoc, Wisconsin on May 8, 1996. Filterable PM, condensable inorganic PM, condensable organic PM, and CO_2 emissions from Malt Kiln No. 6 were measured using EPA Methods 5 (front- and back- half analyses) and 3 (with Orsat analyzer). In addition, a particle size analysis was performed during each test run using an Anderson Mark III cascade impactor. The particle size data were used to estimate filterable PM-10 and PM-2.5 emissions. Three test runs were performed in order to determine the total particulate air emissions from the kiln at various steps of the kiln cycle. Raw data are included in the report. The tests were performed during three hours of production selected by the Wisconsin Department of Natural Resources: (1) latter part of low temperature drying, (2) medium temperature drying and start of high temperature drying, and (3) latter part of high temperature drying, cooling, lower malt bed dumping, and post-dumping ventilation. The CO_2 measurements were close to ambient levels and the CO_2 data were therefore not used for emission factor development.

The facility produces barley malt for the brewing industry. The final step in that process includes the drying of barley malt to a desired moisture content using a “double-deck” (a lower and an upper deck) gas-fired drying kiln. Approximately 9,300 bushels of “wet” malt are loaded onto the upper deck for partial drying during the first stage. Upon completion of the first stage, the partially dried malt is dumped to the lower deck and then “wet” malt is loaded onto the upper deck. The complete drying cycle is approximately 24 hours and includes the following steps: (1) loading and leveling of malt on deck; (2) low temperature drying; (3) medium temperature drying; (4) high temperature drying; (5) cooling; and (6) product dumping. The report states that the flow rate measured during Run 3 was likely an overestimate of actual conditions. The Run 3 flow rate appears to be reasonable compared to the other runs.

Using the data from this report, emission factors, in units of lb/ton of malted barley produced, were developed for filterable PM, PM-10, PM-2.5, condensable inorganic PM, and condensable organic PM emissions from malt kilns. The data were down-rated to B because of the uncertainty associated with the flow rate during Run 3. The test methodology appeared to be sound and the data were complete. Selected pages from the test report as well as applicable calculations are provided in Appendix EE.

4.2 REVIEW OF EXISTING EMISSION FACTORS

In the Interim AP-42 Section 9.9.1, Table 9.9.1-2 presented emission factors for total PM and PM-10 for grain elevators and processing plants. The factors for grain elevators were presented using a “dustiness ratio” concept in which different grain types were assigned a dustiness factor, which was based on the experience of grain industry personnel. Wheat was arbitrarily assigned a factor of 1.0. Test data for different grains were “normalized” to wheat using the dustiness ratio. The source test data used to develop the emission factors were primarily obtained during the 1970s and early 1980s; with few exceptions, more recent emissions data were not available. New source test data have become available for country elevators, terminal elevators, animal feed mills, and malted barley kilns. The new emission factors for grain elevators and processing plants have utilized these new data to the extent possible. The new factors do not incorporate the dustiness ratio concept; a single emission factor is presented for all grain types. Recent source tests using multiple grain types have largely shown that there is no clear distinction in the results based on grain type so that, at this time, separate emission factors based on grain type have not been presented. However, as additional source test data using different grain types at the same site become available, development of emission factors for separate grain types may be possible.

In the development of the new emission factors, the older data have largely been deleted, except in those instances where no more recent data are available. The older data are not considered to be representative of current operations at grain elevators or grain processing plants. In addition, all older source tests were deleted if the "uncontrolled" emission data were based on measurements at the inlet to control devices.

In the Interim section, emission factors for PM-10 were based on the assumption that 25 percent of the total PM was PM-10. The new emission factors for PM-10 are based on source test data and particle sizing data.

For grain receiving operations in the Interim section, a single emission factor was presented for all types of trucks, i.e., emission data for straight trucks and hopper trucks were combined and an emission factor calculated. The new PM emission factors for grain receiving present different factors for straight trucks and hopper trucks. At the present time, emissions from straight trucks unloading with and without "choke flow" have been combined because insufficient data are available to establish separate factors; if additional source test become available, it may be possible to develop these factors.

In Table 9.9.1-3 of the Interim section, emission factors for grain receiving, grain handling, and feed shipping at animal feed mills were not available and users were referred to the grain elevator factors. Grain receiving and feed shipping emissions data are available from recent tests conducted at animal feed mills. Emission factors for feed mills were developed from these data and are presented in Section 4-3.

For this revised AP-42 Section 9.9.1, all of the source emission test reports and other information sources used in the existing Interim section were reviewed, data from new source tests were integrated, older emissions data were deleted as appropriate, and new emission factors developed. The analysis of the data and development of the proposed new emission factors are discussed in Section 4.3.

4.3 DEVELOPMENT OF CANDIDATE EMISSION FACTORS

The following subsections outline the data analysis methodology used to develop candidate filterable PM, condensable PM, and PM-10 (particles $\leq$ 10 µm in aerodynamic diameter) emission factors for grain elevators and processing facilities. The derivation of emission factors for each pollutant are discussed separately.

4.3.1 Data Analysis for Total Particulate Matter

Useful test data for filterable PM emissions were found in References 22, 25, 27, 36, 40, 42, 58, and 61 for grain elevators and References 4, 11, 36, 37, 38, 41, 47, 48, 53, 54, 56, 60, 68, and 69 for grain processing facilities. Although a few of these data sets were rated A or B, most were assigned a rating of C or D, indicating generally questionable or inadequate data quality. Available data are tabulated in Tables 4-12, 4-13 and 4-14.

TABLE 4-12. DATA USED TO DEVELOP FILTERABLE PM AND PM-10 EMISSION FACTORS FOR GRAIN ELEVATORS[a]

Emission source	Type of control	Type of grain	Average measured filterable PM emission factor, lb/ton[b]	Average measured PM-10 emission factor, lb/ton[c]	Data quality rating	Ref No.[d]
Grain receiving (straight truck)	None	Mixed	0.067	--	B	58
		Mixed	0.30	0.059	B	61
Grain receiving (hopper truck)	None	Mixed	0.038	--	B	58
		Mixed	0.032	0.0078	B	61
Grain receiving (railcar)	None	Mixed	0.032	0.0078	B	61
Grain receiving (barge)	None		(f)	(f)		
Grain shipping (truck)	None	Mixed	0.011	--	B	58
		Mixed	0.16	0.029	B	61
Grain shipping (railcar)	None	Mixed	0.027	0.0022		61
Grain shipping (barge)	None		(f)	(f)		
Grain shipping (ship)	None		(f)	(f)		
Headhouse and internal handling operations (legs, distributor, belts, scales, etc.)[e]	None	Mixed	0.061	0.034	B	61
Bin loading (vent)	None	--	NA	NA	--	--
Grain cleaners						
—Stationary enclosed	None	--	NA	NA	--	--
—Internal vibrating	Cyclone	Wheat	0.029	NA	A	22
		Wheat	0.0093		A	22
		NA	0.157		C	25
		NA	0.0897		C	27
		NA	0.0694		C	40
		Wheat	0.0973		C	42
Grain dryers						
—Column dryers	None	Corn	0.21	NA	D	36
		Corn	0.23	NA	D	36
—Rack dryers	None	Corn	3.75	NA	D	36
		Corn	2.3	NA	D	36
	Self-cleaning screens (50 mesh or smaller)	Corn	0.103	NA	D	36
		Corn	0.84	NA	D	36

[a]NA = not available.
[b]Weight of total particulate matter per unit-weight of grain processed. Number of significant figures presented vary depending on raw test data.
[c]Weight of PM-10 per unit-weight of grain processed. Number of significant figures presented vary depending on raw test data.
[d]See list of references. For data taken from Reference 36, see Appendix L.
[e]Exact number of handling operations varies from facility to facility. Newer headhouse systems include grain receiving (truck dump).
[f]No data available that represent current loading and unloading practices for ships and barges.

TABLE 4-13. DATA USED TO DEVELOP FILTERABLE PM AND PM-10 EMISSION FACTORS FOR GRAIN PROCESSING FACILITIES[a]

Emission source	Type of control	Type of grain	Average measured filterable PM emission factor, lb/ton[b]	Average measured PM-10 emission factor, lb/ton[c]	Data quality rating	Ref. No.[d]
Animal feed mills						
— Grain receiving (hopper truck)	None	Corn	0.017	0.0025	B	60
— Grain handling	None					
— Grain cleaners	None					
— Hammermills	Cyclone	Corn, wheat, soybeans	0.121		A	38
		Corn	0.01		C	41
	Baghouse	Oats, barley, alfalfa, corn	0.022		B	37
		NA	0.0021		B	54,56
— Roller mill	Cyclone	Corn, barley	0.15		C	53
— Flaking	Cyclone	Corn, barley	0.15		B	4
— Grain cracker	Cyclone	Corn	0.0242		C	4
— Pellet coolers	Cyclone	Steer feed	0.833		B	4
		Poultry feed	0.917		C	4
		Mixed feed	0.044		C	4
		Poultry feed	0.50		C	4
		Poultry feed	0.28		C	4
		Steer feed	0.32		C	4
		Steer	0.49		C	4
		Corn, wheat, soybeans	0.197		A	38
		Corn, wheat, soybeans	0.037		B	41
		Poultry feed	0.11		C	53
		Dairy feed	0.18		C	53
	High efficiency cyclone[f]	Feed	0.13		B	54, 56
		Mixed feed	0.16		B	4
— Feed shipping (truck)	None	Feed	0.0033	0.0008	B	60
Wheat mills						
— Receiving	None		(e)	(e)		
— Grain handling	None		(e)	(e)		
— Cleaning house separators	Cyclone	Wheat	0.0087		C	36
		Wheat	0.016		C	36
—Roller mill	None	Wheat	70		C	36

TABLE 4-13. (continued)

Emission source	Type of control	Type of grain	Average measured filterable PM emission factor, lb/ton[b]	Average measured PM-10 emission factor, lb/ton[c]	Data quality rating	Ref. No.[d]
Dry corn milling						
— Receiving	None		(e)	(e)		
— Grain handling	None		(e)	(e)		
— Grain cleaning	None		(e)	(e)		
— Grain drying	None		(e)	(e)		
Rice milling						
— Receiving	--	--	NA	NA	--	--
— Grain handling	--	--	NA	NA	--	--
— Dryer column						
• Gas-fired screen	None	Rice	0.068		D	48
• Screen baffle	None	Rice	0.082		D	48
• Gas-fired screen	None	Rice	0.027		D	48
• Gas-fired screen	None	Rice	0.057		D	48
• Vertical screen	None	Rice	0.082		D	48
— Paddy cleaners	Fabric filter	Rice	0.0031		D	47
— Mill house	Fabric filter	Rice	0.27		D	47
— Aspirator	Fabric filter	Rice	0.0030		D	47
— Bran handling	Fabric filter	Rice	0.017		D	47
Barley malting						
— Receiving	Fabric filter	Barley	0.021	NA	C	68
		Barley	0.011	NA	C	68
— Malt kiln						
• Gas-fired kiln	None	Barley	0.55	NA	C	68
		Barley	0.19	0.17 (PM-2.5 = 0.075)	B	69

aNA = not available.

[b]Weight of total particulate matter per unit-weight of grain processed. Number of significant figures presented vary depending on raw test data.

[c]Weight of PM-10 per unit-weight of grain processed. Number of significant figures presented vary depending on raw test data.

[d]See list of references. For data taken from Reference 36, see Appendix L.

[e]See emission factors for grain elevators, Table 4-12.

[f]Equivalent to triple cyclone or modern high efficiency cyclone.

TABLE 4-14. DATA USED TO DEVELOP CONDENSABLE PM EMISSION FACTORS FOR GRAIN PROCESSING FACILITIES

Emission source	Type of control	Ref. No.	Average condensable PM emission factor, kg/Mg (lb/ton)			Type of grain	Data quality rating
			Inorganic	Organic	Total		
Animal feed mill							
—Pellet cooler	Cyclone	38	--	--	0.049 (0.098)	feed	B
		53	--	--	0.0085 (0.017)	poultry feed	C
		53	--	--	0.031 (0.061)	dairy feed	C
Barley malting							
—Gas-fired kiln	None	69	0.038 (0.075)	0.0065 (0.013)	0.044 (0.088)	barley	B

According to the OAQPS guidelines, A- and B-rated data should not be combined with C- or D-rated data to develop emission factors for a particular source. However, in the case of several source categories, we concluded that combining very limited quantities of A- and B-rated data with substantially greater quantities of C- and D-rated data would improve the overall quality of the emission factor. For such cases, inclusion of the C and D data significantly enhances the overall applicability of the emission factor to a greater number of facilities and grain types. However, the rating of average emission factors obtained in this manner was typically D or E.

To derive the candidate filterable and condensable PM emission factors for the above sources, average emission factors were obtained for each test series either directly from the text of the report or by hand calculation from the experimental data (see Appendices B to EE). The individual factors obtained from the reference documents were then tabulated according to type of facility, emission source, and control equipment and the arithmetic mean calculated for each source/control combination.

The data used to develop candidate emission factors developed by the above method are provided in Tables 4-12 and 4-13 for grain elevators and grain processing facilities, respectively. The candidate filterable and condensable PM emission factors ultimately were obtained either by averaging all data sets for a particular source/grain/control combination regardless of quality or by averaging only A- and B-rated data. The decision as to what information should be used to derive the emission factor for a particular combination was based on the quantity and quality of the available information. Details on how the data in Table 4-12 and 4-13 were combined to obtain final filterable PM emission factors and how the data from Table 4-14 were used to obtain condensable PM emission factors are presented in Section 4.4.3.

As shown by Tables 4-12 and 4-13, the emission data used to derive the candidate emission factors are highly variable and typically range over one or more orders of magnitude within a single source/control category. Also, the quantity of available data is usually limited and generally of questionable quality, which is reflected in the low rating assigned to most filterable PM emission factors. Appropriate footnotes are provided explaining the applicability of each emission factor determined in the analysis.

4.3.2 Particle Size Data Analysis[51,52]

Particle size data were provided in References 10, 11, 12, 23, 24, 26, 33, and 35 for a limited number of sources in grain elevators and processing facilities. Because all of the available particle size information was obtained by some type of inertial sizing device (impactor or cyclone), all data were provided in terms of aerodynamic diameter (equivalent unit density spheres) suitable for direct analysis. The procedure used to develop candidate size-specific emission factors for selected source/control categories is described below.

The raw particle size data contained in the various reference documents were reduced to a common format using a family of computer programs developed especially for this purpose (Table 4-15). These programs are BASIC translations of the FORTRAN program SPLIN2, originally developed by Southern Research Institute. The translated version is one that MRI modified to operate utilizing as few as three data points. The program provides a numerical procedure for obtaining a "best-fit" curve for particle-size test data obtained from varied methods (impactors or sizing cyclones) that may have different cut sizes.

TABLE 4-15. COMPARISON OF COMPUTER PROGRAMS

Data configuration	SPLIN2	SPLINRAW
Input requirements:	Largest particle diameter; cumulative mass fractions for all size cuts	Largest particle diameter; incremental mass fractions
Output:	Predicted cumulative weight percentages for selected aerodynamic particle diameters	Predicted weight percentages for selected aerodynamic particle diameters

SPLIN2 is the central portion of the program, which fits the observed particle size data to a smooth curve using spline fits. Spline fits result in cumulative mass size distributions very similar to those which would be drawn using a French curve and fully logarithmic graph paper. In effect, the logarithm of cumulative mass is plotted as a function of the logarithm of the particle size, and a smooth curve with a continuous, nonnegative derivative is drawn.

To analyze the available information, each of the specific data sets described above was processed through the appropriate computer program to obtain the particle size distribution for selected particle diameters. The particle size ranges selected were: $\leq$30 µmA (total suspended particulate or TSP); $\leq$15 µmA (inhalable particulate or IP); $\leq$10 µmA (PM-10); $\leq$5 µmA; and $\leq$2.5 µmA (fine particulate or FP). Copies of the individual computer printouts have been included in Appendix FF. Any calculations conducted manually are also included in Appendix FF.

4.3.3 Candidate Emission Factor Development

Using the results of the data analyses described above, candidate emission factors were compiled for inclusion in Section 9.9.1 of AP-42. The emission factors provided in Tables 4-12 through 4-14 were used to obtain final emission factors, which are in Table 4-16 for grain elevators and Table 4-17 for grain processing facilities. These tables provide candidate emission factors according to type of facility, emission source, and control along with the type(s) of grain to which the emission factors most directly apply. Each emission factor is also rated and footnotes provided to give the reader the maximum amount of useful information relating to the source of the factor and its applicability. The table in which the

TABLE 4-16. SUMMARY OF CANDIDATE PARTICULATE EMISSION FACTORS FOR GRAIN ELEVATORS

Emission source	Type of control[a]	Reference table(s)[b]	Filterable PM emission factor[c]		Emission factor rating	PM-10 emission factor[d]		Emission factor rating
			lb/ton	kg/Mg		lb/ton	kg/Mg	
Grain receiving (straight truck)	None	4-12	0.18[e]	0.090[e]	E	0.059[f]	0.030[f]	E
Grain receiving (hopper truck)	None	4-12	0.035[e]	0.018[e]	E	0.0078[f]	0.0039[f]	E
Grain receiving (railcar)	None	4-12	0.032[f]	0.016[f]	E	0.0078[f]	0.0039[f]	E
Grain receiving (barge)	None		(k)	(k)		(k)	(k)	
Grain shipping (truck)	None	4-12	0.086[e]	0.043[e]	E	0.029[f]	0.015[f]	E
Grain shipping (railcar)	None	4-12	0.027[f]	0.014[f]	E	0.0022[f]	0.0011[f]	E
Grain shipping (barge)	None		(k)	(k)		(k)	(k)	
Grain shipping (ship)	None		(k)	(k)		(k)	(k)	
Headhouse and internal handling (legs, belts, distributor, scale, etc.)[g]	None	4-12	0.061[f]	0.031[f]	E	0.034[f]	0.017[f]	E
Bin loading (vent)	None		NA	NA		NA	NA	
Grain cleaning								
—Stationary enclosed	None		NA	NA		NA	NA	
—Internal vibrating	Cyclone	4-12	0.075[h]	0.038[h]	E	(m)	(m)	
Grain drying —Column dryers	None	4-12	0.22[j]	0.11[j]	E	(m)	(m)	
—Rack dryers	None	4-12	3.0[j]	1.5[j]	E	(m)	(m)	
	Self cleaning screens (<50 mesh)	4-12	0.47[j]	0.24[j]	E	(m)	(m)	

[a] Type of technology used to reduce PM emissions.
[b] Table containing summary data that form the basis of the candidate emission factor.
[c] Weight of total filterable PM, regardless of size, per unit weight of grain throughput.
[d] Weight of PM ≤10 µm in aerodynamic diameter per unit weight of grain throughput.
[e] Mean of two values from References 58 and 61.
[f] Reference 61.
[g] Multiple dust pickup points throughout elevator, depending on configuration.
[h] Mean of six A- and C-rated data points from References 22, 25, 27, 40, and 42.
[j] Mean of two D-rated data points from Reference 36.
[k] No data are available that represent current loading and unloading practices for ships and barges.
[m] PM-10 test data are not available. PM-10 emission factors can be estimated by taking 25 percent of the filterable PM emission factor.

TABLE 4-17. SUMMARY OF CANDIDATE PARTICULATE EMISSION FACTORS FOR GRAIN PROCESSING FACILITIES

Type of facility	Emission source	Type of control[a]	Reference table(s)[b]	Filterable PM emission factor[c]		PM-10 emission factor[d]		Condensable PM emission factor			
				lb/ton	Rating	lb/ton	Rating	Inorganic	Organic	Total	Rating
Animal feed mills	Grain receiving	None	4-13	0.017[e]	E	0.0025[e]	E				
	Grain cleaning	Cyclone		(f)		(f)					
	Grain milling —Hammermills	Cyclone	4-13	0.067[g]	E	(h)					
		Baghouse	4-13	0.012[j]	E	(k)					
	—Flaking	Cyclone	4-13	0.15[m]	E	(h)					
	—Grain cracker	Cyclone	4-13	0.024[m]	E	(h)					
	Pelletizing operations —Pellet coolers[n]	None									
		Cyclone	4-13,4-14	0.36[p]	E	(h)				0.059[q]	E
		High efficiency cyclone[s]	4-13	0.15[r]	E	(h)					
	Feed shipping	None	4-13	0.0033[e]	E	0.0008[e]	E				
Wheat flour mills	Grain receiving	None		(f)		(f)					
	Grain handling (legs, belts, etc.)	None		(f)		(f)					
	Cleaning house separators	Cyclone	4-13	0.012[t]	E	(h)					
	Wheat milling (roller mill)	None	4-13	70[t]	E	(h)					
Dry corn mills	Grain receiving	None		(f)		(f)					
	Grain handling (legs, belts, etc.)	None		(f)		(f)					
	Grain cleaning	None		(f)		(f)					
	Grain drying	None		(f)		(f)					

TABLE 4-17. (continued)

Type of facility	Emission source	Type of control[a]	Reference table(s)[b]	Filterable PM emission factor[c] lb/ton	Filterable PM emission factor[c] Rating	PM-10 emission factor[d] lb/ton	PM-10 emission factor[d] Rating	Condensable PM emission factor Inorganic	Condensable PM emission factor Organic	Condensable PM emission factor Total	Condensable PM emission factor Rating
Rice mills	Grain receiving	None		NA		NA					
	Grain handling	None		NA		NA					
	Rice drying	None	4-13	0.063[u]	E	(h)					
	Paddy cleaners	Fabric filter	4-13	0.0031[v]	E	(k)					
	Mill house	Fabric filter	4-13	0.27[v]	E	(k)					
	Aspirator	Fabric filter	4-13	0.0030[v]	E	(k)					
	Bran handling	Fabric filter	4-13	0.017[v]	E	(k)					
Durum, rye, and oat mills	All operations			(f)		(f)					
Barley malting	Grain receiving	Fabric filter	4-13	0.016[w]	E	(k)					
	Gas-fired malt kiln	None	4-13,4-14	0.19[x]	E	0.17[y] (PM-2.5= 0.075)	E	0.075[y]	0.013[y]	0.088[y]	E

[a] Type of technology used to reduce particulate emissions.
[b] Table from which candidate emission factor data were obtained.
[c] Weight of total filterable particulate matter, regardless of size, per unit weight of grain throughput.
[d] Weight of particulate matter $\leq$ 10 µm in aerodynamic diameter per unit weight of grain throughput.
[e] Reference 60.
[f] See emission factors for grain elevators, Table 4-16.
[g] Mean of two values from Reference 38 and 41.
[h] PM-10 test data are not available. PM-10 emission factors can be estimated by taking 50 percent of the filterable PM emission factor.
[j] Mean of two B-rated values from References 37, 54, and 56.
[k] PM-10 test data are not available. PM-10 emission factors can be estimated by taking 100 percent of the filterable PM emission factor.
[m] Reference 4.
[n] Includes column and pan coolers.
[p] Mean of 11 A-, B-, and C-rated values from References 4, 38, 41, and 53.
[q] Mean of three B- and C-rated values from References 38 and 53.
[r] Mean of two B-rated values from References 4, 54, and 56.
[s] Equivalent to triple cyclone or modern high efficiency cyclone.
[t] Reference 36.
[u] Mean of five D-rated data points from Reference 48.
[v] Reference 47.
[w] Reference 68.
[x] Mean of two values from References 68 and 69.
[y] Reference 69.

emission factor was originally presented is also noted in the fifth column of the table for reference. The paragraphs below describe how the data from Tables 4-12 through 4-14 were used to obtain the emission factors in Tables 4-16 and 4-17.

As noted in Table 4-12, emission data are available for for five general types of operations for grain elevators--grain receiving, grain shipping, headhouse and internal handling operations, grain cleaning, and grain drying. The paragraphs below describe the procedures used to calculate emission factors for each of these sources. For each operation, grain-specific emission factors are calculated if grain type is known and data are adequate to warrant such grain-specific factors. However, general factors that represent general mixtures of grain are calculated if such factors appear to be warranted.

A filterable PM emission factor was developed for uncontrolled grain receiving by straight truck. The emission factor was developed for mixed grains. The mixed grain factor is the mean of two B-rated values from Table 4-12. Because the factor is developed from only two facilities, the emission factor is rated E. A PM-10 emission factor for grain receiving by straight truck was developed from one B-rated value from Table 4-12. Because this factor was developed from only one test, the emission factor is rated E.

A filterable PM emission factor was developed for uncontrolled grain receiving by hopper truck. The emission factor was developed for mixed grains. The mixed grain factor is the mean of two B-rated values from Table 4-12. Because the factor is developed from a limited number of facilities, the emission factor is rated E. A PM-10 emission factor for grain receiving by hopper truck was developed from one B-rated value from Table 4-12. Because this factor was developed from one test problem at grain elevators, the emission factor is rated E.

A filterable PM emission factor was developed for uncontrolled grain receiving by hopper-bottom railcar. The emission factor was developed for mixed grains. The mixed grain factor is developed from a single B-rated value from Table 4-12. Because the factor is developed from one value, the emission factor is rated E. A PM-10 emission factor for grain receiving by hopper-bottom railcar was developed from one B-rated value from Table 4-12. Because this factor was also developed from one value, the emission factor is rated E.

A filterable PM emission factor was developed for uncontrolled grain shipping by truck. The emission factor was developed for mixed grains. The mixed grain factor is the mean of two B-rated values from Table 4-12. Because the factor is developed from only two values, the emission factor is rated E. A PM-10 emission factor for grain shipping by truck was also developed from one B-rated value from Table 4-12. Because this factor was developed from a single source test program, the emission factor is rated E.

A filterable PM emission factor was developed for uncontrolled grain shipping by railcar. The emission factor was developed for mixed grains. The mixed grain factor is developed from a single B-rated value from Table 4-12. The emission factor is rated E. A PM-10 emission factor for grain shipping by railcar was also developed from one B-rated value from Table 4-12; the emission factor is rated E.

A filterable PM emission factor was developed for uncontrolled grain internal handling operations. The emission factor was developed for mixed grains. The mixed grain factor is developed from a single B-rated value from Table 4-12; the emission factor is rated E. A PM-10 emission factor for grain internal handling operations was also developed from one B-rated value from Table 4-12; the emission factor is rated E.

A filterable PM emission factor was developed for cyclone-controlled grain cleaning operations. An emission factor was developed for mixed grains. Two A-rated data points and four C-rated data points from Table 4-12 were combined. The emission factor is rated E because it is not representative of all facilities.

A filterable PM emission factor was developed for uncontrolled grain column dryers for corn. The emission factor is the average of two D-rated data points from Table 4-12. Because the emission factor was generated from D-rated data, the emission factor is rated E.

Two filterable PM emission factors were developed for rack dryers, one for emissions from corn drying with no control and one for emissions from corn drying with self-cleaning screens. Each emission factor is the average of two D-rated data points from Table 4-12. Because all data used to develop these factors are rated D, the emission factors are rated E.

In general, the emission factors for grain processing facilities were obtained by extracting a single value or by averaging two or three values from Table 4-13 or Table 4-14. These emission factors are generally rated E. The primary exceptions are animal feed pellet coolers and rice dryers. The development of these emission factors is discussed below.

A filterable PM emission factor was developed for cyclone-controlled animal feed pellet coolers. The emission factor is the average of eleven A-, B-, and C-rated data points from Table 4-13. Because most of the data are C-rated and because emissions from individual facilities vary by a factor of 25, the emission factor is rated E.

A single filterable PM emission factor was developed for screen-type rice dryers using the arithmetic average of five data points from Table 4-13. Because all five data points were D-rated, the emission factor is rated E.

The data from References 67, 68, and 69 were used to develop emission factors for malted barley production. The data are summarized in Table 4-13 and these candidate emission factors for inclusion in AP-42 are presented in Table 4-17. All of the emission factors are assigned E ratings because they were developed using data from only one or two tests. The development of the individual emission factors is discussed below.

An emission factor was developed for filterable PM from fabric filter-controlled barley unloading operations. This factor is based on two C-rated tests conducted at the same facility. Emission factors were developed for filterable PM, condensable inorganic and organic PM, PM-10, and PM-2.5 from indirect-, natural gas-fired malt kilns using B-rated data from Reference 69. One additional C-rated test (Reference 68) was conducted for filterable PM from malt kilns, but the data were not used because they are inconsistent with the Reference 69 test.

Although every attempt was made to provide an emission factor for every source addressed in the current version of AP-42 Section 9.9.1, data were sometimes insufficient to allow calculation of an emission factor. Also, a number of the uncontrolled factors have been changed and/or rated differently from the current version of AP-42. Noteworthy variations from the existing AP-42 section are described in the paragraphs below.

In the Interim AP-42 section, PM-10 emission factors for grain elevator operations were assumed to be 25 percent of the total PM emission factors; PM-10 emission factors for grain processing operations were assumed to be 50 percent of the filterable PM emission factors. In the revised section, PM-10 emission factors are based on source test data where they are available. For uncontrolled and cyclone-controlled filterable PM sources where no PM-10 emission data are available, PM-10 emission factors are assumed to be 25 percent of the filterable PM emission factors for grain elevators and 50 percent of the filterable PM emission factors for grain processing sources. For fabric filter-controlled sources of filterable PM where no PM-10 emission data are available, PM-10 emission factors are assumed to be 100 percent of the filterable PM emission factors for grain processing sources. These assumed values will be replaced as additional PM-10 and particle sizing data become available.

Some of the current uncontrolled factors were actually based on a back-calculation from cyclone-controlled emissions using an assumed control efficiency for the collector. This approach was not used here. As mentioned in the individual report reviews, it is generally agreed that emission measurements taken at the inlet of a control device do not accurately reflect emissions from uncontrolled sources. It is agreed that the emission estimates based on control device inlet data are biased high for uncontrolled emissions at operations not equipped with aspiration systems. Therefore, control device inlet data have not been used in this report to estimate uncontrolled emissions. The controlled values are presented, however, and rated according to the criteria specified in Section 3 of this report.

Tables 4-16 and 4-17 have been incorporated in the revised AP-42 section shown in Section 5 of this report as Tables 9.4-1 and 9.4-2, respectively. Appropriate modifications have also been made in the text to reflect these revisions.

REFERENCES FOR SECTION 4

1. G. LaFlam, *Documentation for AP-42 Emission Factors: Section 6.4, Grain Elevators and Processing Plants*, Final Report, EPA Contract No. 68-02-3887, Work Assignment No. 54, Pacific Environmental Service Inc., Durham, North Carolina.

2. Letter from David Bossman, American Feed Industry Association to Frank Noonan, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 24, 1987.

3. Letter from Paul Luther, Purina Mills, Inc. to Frank Noonan, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 8, 1987.

*4. Letters (plus attachments) from Paul Luther, Purina Mills, Inc. to Greg LaFlam, Pacific Environmental Service Inc., Durham, North Carolina, March 11 and August 28, 1987.

5. R. F. Ambler et al., *Feed Manufacturing Technology III*, American Feed Industry Association, Arlington, Virginia, 1985.

6. GCA/Technology Division, *Emission Factor Development for Ship and Barge Loading of Grain*, Revised Draft Final Report, EPA Contract No. 68-02-3510, Work Assignment No. 46, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1984.

7. *Source Category Survey: Animal Feed Dryers*, EPA-450/3-81-017, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1981.

8. J. M. Appold, "Dust Control for Grain Dryers." Chapter 11 in *Dust Control for Grain Elevators*, National Feed and Grain Association, Washington, DC, May 7-8, 1981.

9. V. Ramanathan and D. Wallace, *Review of Compliance Monitoring Programs with Respect to Grain Elevators*, Final Report, EPA Contract No. 68-01-4139, Tasks 12 and 14, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 1980.

10. W. Battye and R. R. Hall, *Particulate Emission Factors and Feasibility of Emission Controls for Shiploading Operations at Portland, Oregon Grain Terminals, Volume I,* Final Report, EPA Contract No. 68-01-4143, Task Order Nos. 24 and 47, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, June 1979.

*11. H. J. Taback et al., *Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin. Final Report*, PB-293 923, California Air Resources Board, Sacramento, California, February 1979.

12. W. Battye et al., *Grain Dust Levels Caused by Tent Control of Ship Loading Emissions Compared to Minimum Explosive Levels*, Draft Final Report, EPA Contract No. 68-01-4143, Task Order 47, U.S. Environmental Protection Agency, Washington, DC, December 1978.

13. J. Zoller et al., *Assessment of Fugitive Particulate Emission Factors for Industrial Processes*, EPA-450/3-78-107, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1978.

14. D. R. Goodwin, *Standards Support and Environmental Impact Statement, Volume 2: Promulgated Standards of Performance for Grain Elevator Industry*, EPA-450/2-77-001b, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1978.

15. R. Johnson et al., *Emission Tests at Adolph Coors Company No. 4 Coal-Fired Steam Generator*, Report No. 77-SPP-17, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 26, 1977.

16. R. A. Wachter and T. R. Blackwood, *Source Assessment: Harvesting of Grain, State of the Art*, EPA-600/2-77-107f, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, July 1977.

17. Research Corporation of New England, *Determining Input Variables for Calculation of Impact of New Source Performance Standards: Worksheets for Food and Agricultural Industries*, EPA-450/3-76-018c, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, April 1977.

*18. P. Lonnes, *Results of Particulate Emission Compliance Testing at the Peavey Company in Valley City, North Dakota, Conducted March 16-18, 1977,* Interpoll Inc., St. Paul, Minnesota, April 15, 1977.

19. *Technical Guidance for Control of Industrial Process Fugitive Particulate Emissions*, EPA-450/3-77-010, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 1977.

20. *Standards Support and Environmental Impact Statement, Volume 1: Proposed Standards of Performance for Grain Elevator Industry*, EPA-450/2-77-001a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, January 1977.

21. M. P. Schrag et al., *Source Test Evaluation for Feed and Grain Industry*, EPA-450/3-76-043, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1976.

*22. F. J. Belgea, *Dust Control Systems Performance Test*, Pollution Curbs, Inc., St. Paul, Minnesota, July 15, 1976.

23. W. H. Maxwell, *Stationary Source Testing of a Country Grain Elevator at the Great Bend Cooperative Association Elevator B, Great Bend, Kansas,* Final Report, Contract No. 68-02-1403, Task 19, Midwest Research Institute, Kansas City, Missouri, April 29, 1976.

24. W. H. Maxwell, *Stationary Source Testing of a Country Elevator-Overbrook, Kansas*, Final Report, EPA Contract No. 68-02-1403, Tasks 15 and 18, Midwest Research Institute, Kansas City, Missouri, February 19, 1976.

*25. A. L. Trowbridge, *Particulate Emissions Testing,* ERC Report No. 4-7683, Environmental Research Corporation, St. Paul, Minnesota, January 16, 1976.

26. J. M. Willenberg et al., *Air Pollution Emissions from Eastern Washington Grain Elevators*, Annual Meeting of the Pacific Northwest International Section of the Air Pollution Control Association, November 19-21, 1975.

*27. C. S. Hulburt, *Particulate Emissions Evaluation and Performance Test of the Dust Control Systems at Farmers Coop Elevator in Enderlin, North Dakota*, Pollution Curbs Inc., St. Paul, Minnesota, October 23, 1974.

28. *Emission Factor Development for the Feed and Grain Industry*, EPA-450/3-75-054, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 1974.

29. *Emissions Control in the Grain and Feed Industry: Volume II. Emissions Inventory*, EPA-450/3-73-003b, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, September 1974.

30. P. G. Gorman, *Potential Dust Emissions from a Grain Elevator in Kansas City, Missouri*, Final Report, EPA Contract No. 68-02-0228, Task No. 24, Midwest Research Institute, Kansas City, Missouri, May 1974.

31. *Storage and Handling of Grain*. Final Report, Contract No. 68-02-1355, Task Order No. 7, PEDCo-Environmental Specialists Inc., March 1974.

32. *Development Document for Effluent Guidelines and New Performance Standards for the Grain Processing Segment of the Grain Mills Point Source Category*, EPA-440/1-74-028a, U.S. Environmental Protection Agency, Washington, DC, March 1974.

33. Valentine, Fisher, and Tomlinson, *Air Pollution Emission Test, Cargill, Inc., Seattle, Washington*, EMB Test No. 73-GRN-8, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, January 1974.

34. F. J. Belgea, *Dust Collector Emission and Efficiency Evaluation at the Marquette Elevator*, Pollution Curbs Inc., St. Paul, Minnesota, January 29, 1974.

35. Battelle Memorial Institute, *Air Pollution Emission Test, Bunge Corporation, Destrehan, Louisiana*, EMB Test No. 74-GRN-7, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, January 1974.

*36. L. J. Shannon et al., *Emissions Control in the Grain and Feed Industry, Volume I: Engineering and Cost Study*, EPA-450/3-73-003a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, December 1973.

*37. W. D. Snowden, *Atmospheric Emission Evaluation, Mayflower Farms Grain and Feed Milling Plant, Portland, Oregon*, Test No. 72-CI-34(GRN), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, February 8, 1973.

*38. R. W. Gerstle and R. S. Amick, *Test Number 73-GRN-1, Ralston Purina Company, Louisville, Kentucky*, Final Report, EPA Contract No. 68-02-0237, Task 17, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1972.

39. Environmental Engineering Inc., *Source Test Report on Measurement of Emissions from Cargill, Inc., Fayetteville, North Carolina*, Test No. 72-CI-33(GRN), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1972.

*40. F. J. Belgea, *Grain Handling Dust Collection Systems Evaluation for Farmer's Elevator Company, Minot, North Dakota*, Pollution Curbs Inc., St. Paul, Minnesota, August 28, 1972.

*41. Environmental Engineering Inc., *Source Test Report on Measurement of Emissions from Cargill, Inc., Sioux City, Iowa*, Test No. 72-CI-28(GRN), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1972.

*42. F. J. Belgea, *Cyclone Emissions and Efficiency Evaluation*, Pollution Curbs Inc., St. Paul, Minnesota, March 10, 1972.

43. M. F. Fuller, *Particulate Emission Tests on Cyclone Exhaust at Pillsbury Operated Grain Elevator in Curren, Illinois*, Report No. 26-6-171, Industrial Testing Laboratories Inc., St. Louis, Missouri, June 1972.

44. W. E. Clark, *Sampling of Grain Elevators in Kansas City to Determine Particulate Emissions to the Atmosphere*, Final Report, Midwest Research Institute, Kansas City, Missouri, October 20, 1966.

45. Letter from Thomas C. O'Connor, National Grain and Feed Association, to Dallas Safriet, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, November 24, 1993.

46. F. S. Lai, C. R. Martin, and B. S. Miller, *Examining the Use of Additives to Control Grain Dust.* Final Report to National Grain and Feed Association. U. S. Department of Agriculture, Manhattan, Kansas, June 1982.

*47. Thomas Rooney. *Emission Performance Testing of a Rice Mill*, Western Environmental Services, Redondo Beach, CA, March 1992.

*48. Letter from W. James Wagoner, Butte County Air Pollution Control Agency to Dallas Safriet, U. S. Environmental Protection Agency, Research Triangle Park, NC. October 11, 1993.

49. *Report on Emissions from Rice Dryers in the Sacramento Valley Air Basin*, CARB Report No. 74-8-8. California Air Resources Board, Sacramento, CA, April 1974.

50. Letter from D. Marlin Brandon, California Cooperative Rice Research Foundation, Inc. to R. M. Sandrock, Farmers Rice Cooperative, Sacramento, CA, October 22, 1993.

51. J. W. Johnson et al., *A Computer-Based Cascade Impactor Data Reduction System*, EPA-600/7-78-042, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, March 1978.

52. J. S. 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, North Carolina, February 1987.

*53. *Report Of Particulate Emissions Tests For Stockton Hay And Grain Company*, Environmental Research Group, Inc., Emeryville, CA, September 1983.

*54. *Particulate Emission Testing For Wayne Farms Sandersville, Mississippi*, Air Systems Testing, Inc., Marietta, GA, September 1-2, 1992.

55. Letter from Brian L. Bursiek, American Feed Industry Association to Dallas Safriet, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, October 23, 1995.

*56. *Report Of Particulate Emissions Tests For Wayne Farms Laurel Feed Mill, Laurel, Mississippi*, Environmental Monitoring Laboratories, Ridgeland, MS, August 29 and September 20, 1994.

57. *Tests of Oil Suppression Of PM-10 At Grain Elevators*, Test Report, Midwest Research Institute, Kansas City, MO, November 1994.

*58. P. Kenkel and R. Noyes, "Grain Elevator Dust Emission Study", Oklahoma State University, Stillwater, OK, October 21, 1994 and "Clarifying Response To MRI Report On OSU Dust Emission Study", Oklahoma State University, Stillwater, OK, February 13, 1995.

59. Bay Area Air Quality Management District, Summary of Source Test Results, Willowbrook Feeds, Petaluma, California, October 26, 1995.

*60. *Emission Factors for Grain Receiving and Feed Loading Operations at Feed Mills*, for National Cattleman's Beef Association, Texas A&M University, College Station, Texas, September 17, 1996.

*61. *Emission Factors for Grain Elevators*, Final Report to National Grain and Feed Foundation, Midwest Research Institute, Kansas City, Missouri, January, 1997.

62. F. J. Wade, et al., "Investigation To Determine Dust Concentration And Characteristics Inside Enclosed Work Areas And Equipment At Large Grain Terminals", U. S. Department Of Agriculture, Federal Grain Inspection Service, Kansas City, MO, 1979.

63. G. Ryan and G. Flibbert, "*Grain Particulate Study for Eastern Washington Grain Handling Facilities*", Washington State Department of Ecology, 1994.

64. California Warehouse Association, Pooled Source Test Data, Farmer's Rice Cooperative, Dos Palos, California, July 27, 1989.

65. Southwestern Laboratories, Inc., *Compliance Emissions Testing of Center Ship Loading Dust Collector Galena Park Facility*, Woodhouse Corporation, Galena Park, Texas, Project No. 54-9010-419, January 15, 1991.

66. Letter from Brian L. Bursiek, American Feed Industry Association to Dallas Safriet, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, November 1, 1995.

67. *Compliance Test Report for the Determination of Nowmethane Organic Compound Emissions from the No. 15 Kiln Malt Dryer Exhaust, Prepared for Ladish Malting Company, Jefferson Junction, WI,* Fluid Management, Inc., Milwaukee, Wisconsin, December 1995.

*68. H. J. Beaulieu, *Final Report Atmospheric Emission Testing Busch Agricultural Resources, Inc., Idaho Falls Malt Plant*, Industrial Hygiene Resources, Ltd., Boise, Idaho, October, 1991.

*69. M. J. Huenink, *Total Particulate Emissions Stack Testing of the Kiln 6 Operations at Busch Agricultural Resources, Inc., Manitowoc, Wisconsin,* Environmental Technology and Engineering Corp., Elm Grove, Wisconsin, May 8, 1996.

*Contains emission data used in developing emission factors.

5. PROPOSED AP-42 SECTION 9.9.1

The proposed AP-42 Section 9.9.1, Grain Elevators and Processing Plants, is presented on the following pages as it would appear in the document.