Draft

Technical Background Document on Control of Fugitive Dust at Cement Manufacturing Facilities

March 20, 1998

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Chapter 1: Introduction

1.1 Background and Approach

In its Regulatory Determination on cement kiln dust (CKD) published in 1995 (60 FR 7366), EPA concluded that additional control of CKD is warranted in order to protect the public from human health risks and to prevent environmental damage resulting from current methods of managing and disposing the waste. Among the environmental concerns posed by the waste and these management and disposal methods, the Agency identified potential risks to human health from inhalation of particulate material (pm). In response, EPA conducted a number of analyses to identify and evaluate options for the control of fugitive emissions from the management and disposal of the CKD waste. These analyses included researching and evaluating several technologies for controlling fugitive dust emissions and analyzing the possible reductions in fugitive dust emissions that might be achieved through implementing the technologies.

The objective of these analyses was to develop tailored technical standards that not only are protective of human health and the environment but also are sufficiently flexible to allow facility owners and operators to tailor their management approach to site specific conditions. To develop the proposed standards, EPA evaluated the results of risk modeling and damages resulting from documented cases of releases of toxic constituents, and conducted an emissions reduction analysis to evaluate the effectiveness of a suite of fugitive dust control technologies. Based on the results of these analyses, EPA developed and is proposing a performance standard, technology-based standards, and backup tailored Subtitle C standards to minimize the impact of CKD management and disposal practices on ambient air quality at, and surrounding, cement manufacturing facilities.

1.2 Summary of Proposed Standards

EPA is proposing a performance of standard that requires covering or otherwise managing CKD to control fugitive dust. The proposed standards will apply to new and existing cement kiln dust landfills, except units closed prior to the effective date of the rule. To meet the standard, the owner/operator would cover or otherwise manage CKD in a manner to control wind dispersal.

To meet the performance standard, EPA also is proposing technology-based design standards for three key points in the CKD management and disposal handling train. These points are: (1) the point of temporary storage of CKD at the facility after it is removed from a dust collection device prior to sale or final disposal; (2) trucks that transport of the CKD to the disposal site; and (3) disposal of the CKD in an on-site landfill or monofill. EPA is proposing the following technnology standards for these emission points:

1. Temporary storage at the facility: enclosure (e.g., in a tank, building, or container);

2. Transport of CKD from the plant to the landfill or monofill: covered trucks; and

3. Landfill disposal: conditioned CKD covered by a barrier that prevents erosion.

1.3 Organization of this Document

This Technical Background Document (TBD) summarizes the basis for EPA's proposed performance standards and technology-based standards for controlling fugitive emissions of CKD. Chapter 2 provides an overview of the reasons for the Agency's concern regarding fugitive dust, including the physical and chemical characteristics of CKD; the physical/climatological settings at cement facilities; and current CKD management practices. This chapter also discusses EPA's reasons for developing fugitive dust control standards, including descriptions of documented air damages, estimates of population effects from exposure to airborne CKD, and on-site observations. Chapter 3 describes the technology options for controlling CKD air emissions that EPA examined and the estimated effectiveness of each option. Chapter 4 identifies the proposed standards for controlling fugitive dust. Chapter 5 discusses issues related to implementation of the proposed standards and provides estimates of emissions following application of the proposed technology-based standards at two example facilities.

Chapter 2: Reasons for Agency Concern

In the *Report to Congress on Cement Kiln Dust* (EPA 1993) and the subsequent *Notice of Data Availability* (NODA) (EPA 1994) and *Regulatory Determination* (60 FR 7366), EPA presented data showing that CKD contains certain Appendix VIII metals (40 CFR Part 261 "Hazardous Constituents") and low concentrations of dioxin and dibenzofuran. In the *Report to Congress*, EPA documented evidence of damage to ground water, surface water, and air and identified potential risks to human to human health and the environment from on-site management of CKD. The results of the direct inhalation exposure modeling conducted for the *Report to Congress*, which modeled the intake of toxic metals, dioxins, and radionuclides, predicted only low or negligible risk potential from on-site management of CKD via direct inhalation of air containing particulate CKD. However, additional analyses reported in the NODA showed found evidence of possible risk to human health due to the fine particulate nature of inhaled dust. Furthermore, in a follow-up study conducted in 1997 of the population effects due to exposure to airborne particulate matter released from CKD management activities, EPA estimated that up to 2,400 individuals living within 500 meters (m) of the facility boundary of 108 cement facilities may be exposed to airborne particulate matter concentrations in excess of the National Ambient Air Quality Standards for particulate matter (USEPA, 1997).

This chapter provides an overview of the reasons for the Agency's concern regarding fugitive dust, including the physical and chemical characteristics of CKD; the physical/climatological settings at cement facilities; and current CKD management practices. This chapter also discusses EPA's reasons for developing fugitive dust control standards, including descriptions of documented air damages and on-site observations. Estimates of population effects from exposure to airborne CKD are provided in the *Technical Background Document: Population Risks from Indirect Exposure Pathways, and Population Effects from Exposure to Airborne Particles from Cement Kiln Dust Waste* in the docket for this rule (USEPA, 1997).

2.1 Waste Characteristics

Cement plants produce a considerable quantity of particulate matter as a result of the continuous feeding of raw materials into the cool end of the cement kiln, processing, and the rapid countercurrent flow of combustion gases over the raw feed. Particles that become entrained in combustion gases and are removed from the kiln by exhaust gases are known as CKD. This material is comprised of unchanged raw materials, dehydrated clay, decarbonated (calcined) limestone, ash from fuel, and newly formed minerals produced by the chemical transformation of raw materials during the cement manufacturing process. The physical and chemical properties and toxicity of CKD are described below.

2.1.1 Physical Characteristics

Fresh CKD is a fine, dry alkaline dust that readily absorbs water. CKD particle sizes generally vary by kiln process type (see Exhibit 2-1) and range from 0-5 micrometers (μm) (approximately clay size) to greater than 50 μm (silt size) (EPA 1993).

Exhibit 2-1
Particle Size Distribution of CKD by Process Type

Particle Size (μm)	Unspecified Process Type[a] (weight percent)	Wet Kilns[b] (weight percent)	Long Dry Kilns[b] (weight percent)	Dry Kilns with Precalciner[b] (weight percent)
0-5	5	26	45	6
5-10	10	19	45	11
10-20	30	20	5	15
20-30	17	9	1	23
30-40	13	8	1	18
40-50	7	1	0	9
>50	18	17	3	18
Median Particle Size	**No Data**	**9.3**	**3.0**	**22.2**

[a] Kohlhaas, B., et al., 1983. Cement Engineer's Handbook. Bauverlag GMBH, Wiesbaden and Berlin. p. 635. The number of samples used to develop data was not specified.

[b] Todres, H., A. Mishulocich, and J. Ahmed, 1992. CKD Management: Permeability. Research and Development Bulletin RD103T, Portland Cement Association, Skokie, Illinois, p. 2.

2.1.2 Chemical Characteristics

The primary bulk constituents in CKD (those found in quantities greater than 0.05 percent by weight) are silicates, calcium oxide, carbonates, potassium oxide, sulfates, chlorides, various metal oxides, and sodium oxide. EPA data also suggest that variability in raw feed, fuels, process types and product specifications may influence CKD chemical characteristics (EPA 1993).

CKD contains certain metals listed in 40 CFR 261 Appendix VIII ("Hazardous Constituents"). Exhibit 2-2 presents the range of total concentration levels for a number of metals identified in CKD.

Volatile and semi-volatile organic compounds are generally not found in CKD. However, generally low concentrations of 2,3,7,8-substituted dioxin (0.5 to 20 parts per trillion [ppt]), and 2,3,7,8-substituted dibenzofuran (non-detected to 470 ppt) have been detected (60 FR 7366).

Exhibit 2-2
Trace Metal Concentrations in CKD [mg/kg (parts per million), total basis] [a]

Analyte	No. of Samples	Mean	Minimum	Maximum
Antimony	52	11.5	0.99	102
Arsenic	60	14.1	0.26	80.7
Barium	59	181	0.43	900
Beryllium	53	1.03	0.1	6.2
Cadmium	61	9.7	0.005	44.9
Chromium	61	31.2	3.9	105
Lead [b]	63	287	3.1	2620
Mercury	57	0.33	0.003	2.9
Nickel	45	19.9	3	66
Selenium	52	12.2	0.1	103
Silver	56	5.9	0.25	40.7
Thallium	57	33.5	0.44	450

(From 60 FR 7366)

[a] Metals data sources include 1992 PCA, EPA sampling data, and public comments on the RTC.
[b] The median value for lead is 113 mg/kg.

2.2 Plant Settings

This section describes the physical settings in which CKD is managed and the climatological factors that influence the emission of fugitive dust.

2.2.1 Physical Setting

As described in greater detail in Section 2.3.2 of this document, CKD is typically disposed in large, unlined piles in a retired portion of the limestone quarry co-located with the cement plant. These quarries can be as large as a square mile in area and typically have little or no wind barriers at their edges. Consequently, CKD managed within a quarry may be exposed to prevailing winds, increasing the potential for fugitive emissions.

2.2.2 Climatological Factors

The climatological factors that most readily influence fugitive dust emissions are wind speed and rainfall. In general, the potential for fugitive emissions is expected to be greater in locations that are subject to frequent gusts of wind or sustained winds. Fugitive emissions are less likely to occur during precipitation events, primarily due to the tendency of CKD to readily absorb water and form an externally weathered crust, due to absorption of moisture and subsequent cementation of dust particles on the surface of the pile. Precipitation also serves to remove suspended particles from the air.

As a means of characterizing the potential for fugitive emissions at cement plants, EPA reviewed annual mean wind speed and annual average precipitation data that were compiled for the Agency's human health and environmental risk assessment prepared in support of the regulatory determination on CKD (EPA 1994). EPA compiled climatic and meteorologic data for the 61 cement plants that were known in 1990 to generate net CKD (i.e., CKD that is either disposed or used beneficially off-site), the study year for the Portland Cement Association's (PCA) first survey of the industry (PCA 1992).[1]

Annual mean wind speed and annual average precipitation for each of the 61 cement plants are provided in Exhibit 2-3. The exhibit also includes selected descriptive statistics for both parameters, including the mean, median, mode, standard deviation, minimum, and maximum values. The exhibit shows that the median annual mean wind speed for the 58 facilities for which data were available is about 4 m/s (9 miles per hour (mph)); annual mean wind speeds range from 2.6 to 5.8 m/s (5.9 to 13 mph). The median annual average precipitation for the 57 facilities for which data were available is 88.3 centimeters per year (cm/yr) (34.8 inches per year (in/yr)); annual average precipitation for these facilities ranges from 12.5 to 157 cm/yr (4.9 to 61.9 in/yr).

2.3 Management Practices

This section describes CKD waste management practices currently used by the cement industry. Usually 98 to 100 percent of all particulate matter generated during cement production is captured by air pollution control devices before exiting the kiln system (EPA 1993). This gross CKD may be recycled, treated and reused, taken off-site for beneficial use, or disposed of in waste management units (WMUs) (Figure 2-1).

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[1] These data are contained in the risk factors data base provided in Attachment 1-1 of the *Technical Background Document for the Notice of Data Availability on Cement Kiln Dust, Human Health and Environmental Risk Assessment, in Support of the Regulatory Determination on Cement Kiln Dust,*August, 1994.

Exhibit 2-3
Annual Mean Wind Speed and Annual Average Precipitation for 61 Cement Plants

Company Name	City	ST	Annual Mean Wind Speed		Annual Average Precipitation	
			(m/s)	(mi/hr)	(cm/yr)	(in/yr)
Ash Grove Cement Co. - Chanute	Chanute	KS	4.31	9.65	87.8	34.6
Ash Grove Cement Co. - Foreman	Foreman	AR	3.53	7.91	125.5	49.4
Ash Grove Cement Co. - Inkom	Inkom	ID	4.51	10.1	29	11.4
Ash Grove Cement Co. - Louisville	Louisville	NE	3.67	8.22	73.8	29.1
Ash Grove Cement Co. - Montana City	Montana City	MT	3.69	8.27	33.1	13
Blue Circle Inc. - Ravena	Ravena	NY	4.19	9.39	88.3	34.8
Calif. Portland Cement - Mojave	Mojave	CA	3.89	8.71	12.5	4.9
Capitol Aggregates, Inc.	San Antonio	TX	3.71	8.31	74.5	29.3
Continental Cement Co., Inc.	Hannibal	MO	4.67	10.46	80.8	31.8
Dacotah Cement	Rapid City	SD	5.18	11.6	47.9	18.9
Essroc Materials - Bessemer	Bessemer	PA	4.22	9.45	89	35
Essroc Materials - Logansport	Logansport	IN	4.3	9.63	101	39.8
Essroc Materials - Speed	Speed	IN	3.82	8.56	107.8	42.4
Giant Cement Company	Harleyville	SC	3.83	8.58	115	45.3
Heartland Cement Company	Independence	KS	4.31	9.65	87.8	34.6
Holnam Inc. - Ada	Ada	OK	4.49	10.06	88.4	34.8
Holnam Inc. - Artesia	Artesia	MS	2.63	5.89	136.2	53.6
Holnam Inc. - Clarksville	Clarksville	MO	4.67	10.46	80.8	31.8
Holnam Inc. - Devil's Slide Plant	Morgan	UT	3.66	8.2	34.9	13.7
Holnam Inc. - Dundee	Dundee	MI	4.8	10.75	74.8	29.4
Holnam Inc. - Fort Collins	Laporte	CO	5.81	13.01	74.9	29.5
Holnam Inc. - Holly Hill	Holly Hill	SC	3.83	8.58	115	45.3
Holnam Inc. - Midlothian	Midlothian	TX	NA	NA	NA	NA
Holnam Inc. - Portland Plant	Florence	CO	4.15	9.3	31	12.2
Holnam Inc. - Seattle	Seattle	WA	3.31	7.41	90.9	35.8
Holnam Inc. - Tijeras	Tijeras	NM	4	8.96	NA	NA
Independent Cement Corp. - Catskill	Catskill	NY	3.15	7.06	92.3	36.3
Independent Cement Corp. - Hagerstown	Hagerstown	MD	3.4	7.62	86.5	34.1
Kaiser Cement Corp.	Permanente	CA	NA	NA	NA	NA
Keystone Cement Company	Bath	PA	NA	NA	NA	NA
Kosmos Cement Co. - Pittsburgh	Pittsburgh	PA	3.98	8.92	91.8	36.1
Lafarge Corporation - Alpena	Alpena	MI	4.01	8.98	73.4	28.9
Lafarge Corporation - Balcones	New Braunfels	TX	3.71	8.31	71.6	28.2
Lafarge Corporation - Davenport	Buffalo	IA	4.52	10.12	86.1	33.9
Lafarge Corporation - Fredonia	Fredonia	KS	4.31	9.65	87.8	34.6
Lafarge Corporation - Joppa	Grand Chain	IL	3.63	8.13	157.2	61.9
Lafarge Corporation - Paulding	Paulding	OH	4.23	9.48	79.4	31.3
Lafarge Corporation - Sugar Creek	Sugar Creek	MO	4.54	10.17	90.7	35.7

Company Name	**City**	**ST**	**Annual Mean Wind Speed**		**Annual Average Precipitation**	
			(m/s)	**(mi/hr)**	**(cm/yr)**	**(in/yr)**
Lehigh Portland Cement Co. - Cementon	Cementon	NY	3.15	7.06	92.3	36.3
Lehigh Portland Cement Co. - Mason City	Mason City	IA	5.12	11.47	74.4	29.3
Lehigh Portland Cement Co. - Mitchell	Mitchell	IN	3.82	8.56	107.8	42.4
Lehigh Portland Cement Co. - Union Bridge	Union Bridge	MD	4.02	9	99	39
Lone Star Industries - Cape Girardeau	Cape Girardeau	MO	3.65	8.18	109	42.9
Lone Star Industries - Greencastle	Greencastle	IN	4.3	9.63	101	39.8
Lone Star Industries - Nazareth	Nazareth	PA	4.03	9.03	97.8	38.5
Lone Star Industries - Oglesby	Oglesby	IL	4.29	9.61	87.6	34.5
Medusa Cement Company - Charlevoix	Charlevoix	MI	3.88	8.69	75.8	29.8
Medusa Cement Company - Demopolis	Demopolis	AL	2.95	6.61	126.3	49.7
Medusa Cement Company - Wampum	Wampum	PA	3.98	8.92	89	35
National Cement Co. of California - Lebec	Lebec	CA	3.09	6.92	47.5	18.7
Rinker Portland Cement Corp.	Miami	FL	4.58	10.26	139.1	54.8
River Cement Company	Festus	MO	3.65	8.18	109	42.9
Roanoke Cement Company	Cloverdale	VA	3.35	7.5	101.7	40
Signal Mountain Cement Company	Chattanooga	TN	2.84	6.36	135.8	53.5
Southdown - Fairborn	Fairborn	OH	4	8.96	93.9	37
Southdown - Knoxville	Knoxville	TN	2.84	6.36	135.8	53.5
Southdown - Lyons	Lyons	CO	4.15	9.3	31	12.2
Southdown - Odessa	Odessa	TX	4.86	10.89	35.4	13.9
Southdown - Victorville	Victorville	CA	3.68	8.24	38.7	15.2
Tarmac Florida (Fl. Cement Plant)	Medley	FL	4.58	10.26	139.1	54.8
Texas Industries - Midlothian	Midlothian	TX	3.71	8.31	71.6	28.2
	Mean		3.99	8.93	86.6	34.1
	Median		3.99	8.94	88.3	34.8
	Mode		4.31	9.65	87.8	34.6
	Standard Deviation		0.61	1.37	31.5	12.4
	Minimum		2.63	5.89	12.5	4.9
	Maximum		5.81	13.01	157.2	61.9
	Count		58	58	57	57

In 1995, the cement industry consisted of 110 plants operated by 46 companies (PCA 1996), slightly differing from the 111 plants operated by 46 companies in 1992 (EPA 1995). The five largest clinker producing states are California, Texas, Pennsylvania, Michigan, and Missouri.

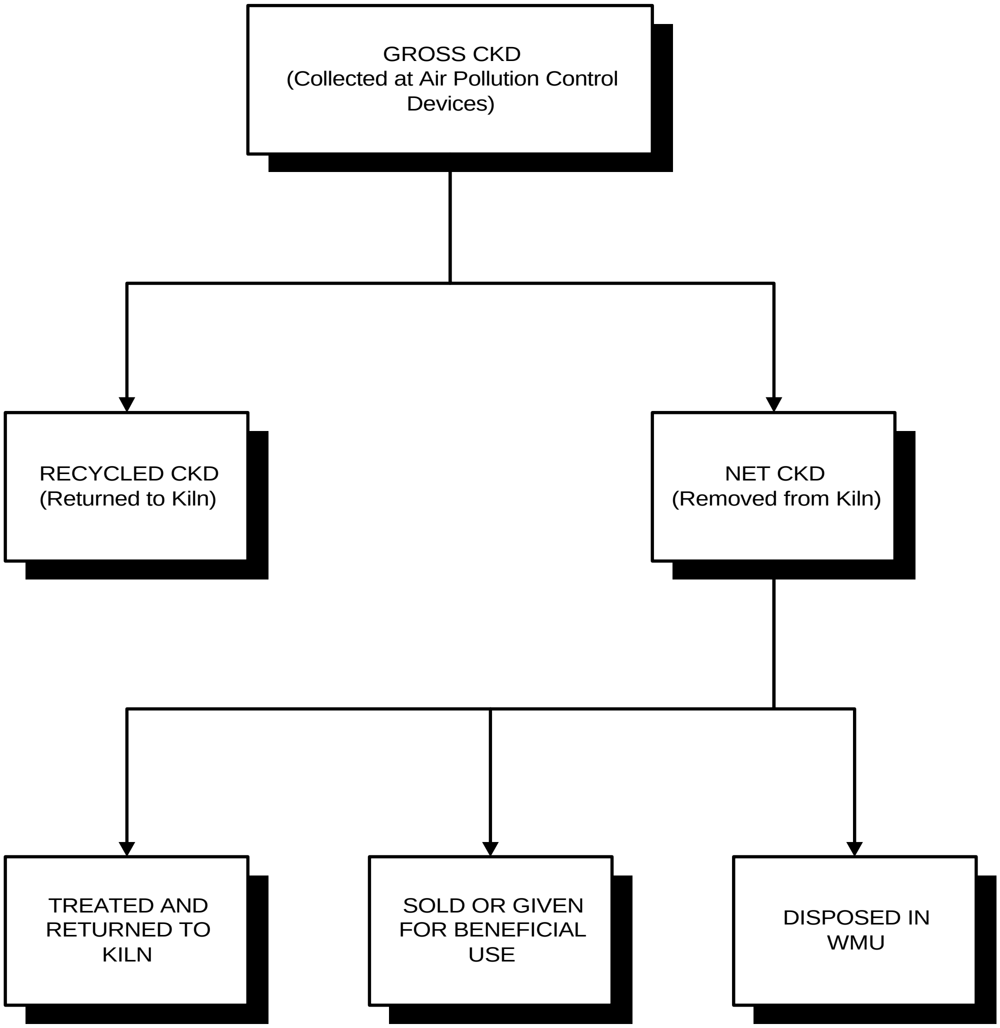

Figure 2-1. Flow Chart of Gross CKD Management Practices.
(Adapted from EPA, 1993a)

Large amounts of high Btu fuels, primarily coal and other fossil fuels, are used during the cement manufacturing process to maintain adequate temperatures within kilns. Currently, 18 cement plants use a mixture of fuels that including RCRA hazardous wastes (EPA 1998).

The Portland Cement Association estimated that 11.7 million metric tons of gross CKD (that is, CKD that is collected by air-pollution control devices) were generated in 1995 (1995 PCA CKD Survey) . This is a decrease from the 12.7 million metric tons of gross CKD generated in 1990. Wide variations exist between kilns in the amount of net CKD that is generated (i.e., CKD that is either disposed or used beneficially off-site). Several cement plants are able to recycle all of their gross CKD back into the kiln (i.e., no net CKD produced). In 1995, the industry recycled 7.8 million metric tons of all CKD generated. EPA reported in the RTC that there is a correlation between plants that burn hazardous waste and the volume of dust that is actually disposed. Kilns that burn hazardous waste remove from the kiln system an average of 75 to 104 percent more dust per ton of clinker than kilns that do not burn hazardous waste (60 FR 7366).

2.3.1 Recycling

Most facility operators recycle CKD to some degree. Based on data from a 1995 PCA survey (representing usable data from 106 facilities), 71 facilities (67 percent) recycled some of their gross CKD, and 24 facilities were able to recycle all of their gross CKD (PCA 1997). In 1995, two-thirds of the gross CKD that was generated by the cement industry - 7.8 million metric tons - were recycled directly back into the kiln or raw feed system. If a cement plant achieves 100 percent recycling, alternative CKD management practices, such as disposal, are deemed unnecessary. However, direct recycling generally results in a gradual increase in the alkali and metals content of generated dust that may damage cement kiln linings, produce inferior cement, and increase particle emissions from the kiln stack. Depending on the quality of the raw materials used, increased concentrations of chloride and sulfur in cement may produce structurally-defective concrete. Some CKD removal from the kiln system as waste is therefore usually necessary (EPA 1993).

Several cost-effective treatment technologies are available or are being developed to treat CKD with high concentrations of alkalies and/or other undesirable constituents before re-entry to the kiln system. At some cement plants, dust reuse is preceded by pelletizing (several plants), mixing with water to leach out alkali salts (used at two plants), or processing through a recovery scrubber (the flue gas desulfurization process) to remove soluble alkalies, chlorides, and sulfates (used at one plant). Pelletizing gives CKD the strength to withstand firing upon re-entry into the kiln system without resuspending large quantities of particulate matter or changing the chemical characteristics of clinker. The leaching process increases the amount of recyclable CKD but generates wastewater that must be treated for high pH values and high concentrations of dissolved and suspended solids. However, no wastewater discharge is associated with this procedure. At one facility, a modified version of this leaching and return process reportedly results in 100 percent recycling of CKD (EPA 1993).

In addition, the Agency has received some evidence, in comments from cement companies on the Report to Congress, that raw material substitution may be a highly effective means of increasing CKD recycling rates. This may be done by controlling the input of contaminants (in raw materials and fuels) to the kiln system, thereby reducing or eliminating the need to purge the kiln system of contaminants (60 *FR* 7366, February 7, 1995; document no. CKDP-0002 in the RCRA docket F-98-CKDP-FFFFF).

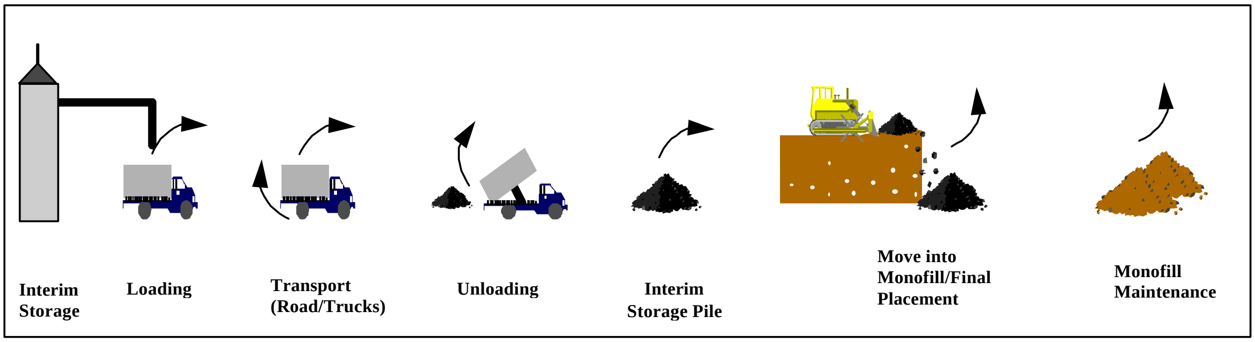

Figure 2-2: Typical CKD transport and disposal sequence. Arrows show common points of fugitive emission of dust.

2.3.2 Temporary Storage, Transport, and Disposal

CKD that is removed from the kiln and not intended to be sold for beneficial use or treated and returned to the kiln is typically disposed on-site. This section focuses on the temporary storage of wasted CKD after it is collected from the air pollution control device and its subsequent transport to the final point of disposal.

CKD is usually removed from air pollution control devices (APCs) and transported to a temporary location near the device by some means of mechanical conveyance, such as a conveyer belt, screw conveyor, or pneumatic conveyor. After being removed from these APCs, CKD is usually held in silos or short-term piles on the ground near the point of removal before it is conveyed to the disposal area. (See Figure 2-2.) This temporary delay in the management and disposal train, referred to in this document as “interim storage at the facility,” varies from hours to days depending on the operating level of the facility. Facilities that convey CKD to the disposal areas in trucks (which include the majority of the industry) attempt to maximize the volume of the load carried on each trip, resulting in the need to stockpile dust at the facility in periods of decreased production. Some facilities, in lieu of truck transport, transport CKD to the disposal area via pneumatic conveyors.

Transport of CKD from the plant to the landfill area may begin immediately after dust is removed from the APC, or it may start at the interim storage area. Transport may proceed from either of these two locations directly to the landfill, or it may end at a temporary storage area near the landfill. As with the need to temporarily store dust after removing it from APCs, the timing of these procedures depends upon the operating level of the facility.

In most cement manufacturing facilities, at least a part, if not all, of the route traveled by CKD haul trucks is unpaved. The length of this route varies among facilities, typically ranging from less than a mile to three miles, round trip. To reduce dust emissions from the haul road’s surface, many (but not all) facilities employ some means and frequency of road wetting to suppress dust.

Similarly, some facilities cover their haul trucks to reduce CKD emissions from the truck beds during the trip to the disposal area.

At the disposal area, CKD is commonly dumped in a series of temporary storage piles at the edge of the final disposal area. Temporary storage near the landfill is necessary when operating levels are such that a bulldozer cannot be operated full-time at the disposal area. This temporary delay in disposal is referred to in this document as “temporary storage near the landfill” and, as with interim storage at the facility, varies from hours to days depending on the operating level of the facility. For final disposal of the dust, the most common management practice is bulldozing the temporary storage piles into an unlined, retired portion of the limestone quarry associated with the cement plant. CKD is also often dumped in large unlined piles at other on-site locations. CKD fugitive emissions are typically generated by wind erosion and dispersal of these open or exposed piles.

According to the 1991 PCA survey (representing usable data from 79 plants and 145 kilns), in 1990, land-disposed CKD averaged 33,000 metric tons per plant, and land-disposed CKD from the entire cement manufacturing industry was estimated to be 3.3 million metric tons (PCA 1991). Typically, WMUs are on-site, non-engineered, unlined and uncovered landfills and piles located in abandoned quarries, retired portions of operating quarries, or nearby ravines. Some active piles are also managed underwater or adjacent to surface water and/or agricultural lands (60 FR 7366). From the 1991 PCA survey (EPA 1993), in 1990, 52 percent of active WMUs were landfills, 43 percent were piles, and less than one percent were ponds. The average pile was 15 meters (15 m) (49.2 ft) thick or 1 m (3.3 ft) thicker than the average landfill. Maximum reported thicknesses for landfills and waste piles were 56.4 m (185 ft) and 34.6 m (113.5 ft) respectively. However, the average basal area for landfills (7.9 hectares (19.5 acres)) was approximately twice that of piles (3.6 hectares (8.9 acres)). Landfills may therefore cover significantly larger land areas than piles. In contrast, the average basal area of ponds was less than one hectare.

Non-CKD waste materials such as furnace brick, concrete debris, and tires may be co-disposed with CKD in WMUs. Responses to the 1991 PCA survey reveal that in 1990 of 66 WMUs, 23 percent co-disposed non-CKD material amounting to one percent of the material disposed in these units.

Approximately half of the facilities use some form of dust suppression/control such as wetting, compacting, or covering the CKD pile or landfill. About 30 to 40 percent of the facilities compact CKD in their active CKDLFs (EPA 1993).

2.3.3 Beneficial Use

CKD may be sold or given away for off-site applications. Beneficial uses of waste CKD include the stabilization of municipal sewage sludges, waste oil sludges, and contaminated soils; the neutralization of acid mine drainage; the addition to agricultural lands as a fertilizer and/or liming agent, and inclusion in Portland cement as a materials additive. In 1995, about six percent of the

CKD generated (658,000 metric tons) was use off-site in beneficial applications (PCA, 1997). Mostly, CKD was used as waste stabilizer, liming agent, and materials additive.

2.4 Documented Air Damages

In the *Report to Congress on Cement Kiln Dust* several cases referencing emissions of cement kiln dust (CKD) were noted. Three cases involving violations of air quality regulations regarding fugitive emissions are included here. (It is important to note that these violations are not examples of stack emissions but of fugitive dust violations.)

2.4.1 Holnam, Inc., Ada, Oklahoma

The Oklahoma State Department of Health issued a Notice of Violation on July 23, 1991 to Holnam, Inc of Ada, Oklahoma for excessive particulate emissions from kiln dust storage area blowing off of the plant's property.

2.4.2 Keystone Portland Cement, Bath, Pennsylvania

Between May 22, 1979 and February 1, 1980 the Pennsylvania Department of Environmental Resources notified Keystone Portland Cement of Bath, Pennsylvania of various dust emissions violations, including fugitive particulate emissions caused by area air contamination sources. A Notice of Violation (NOV) and Consent Order was issued August 27, 1980.

2.4.3 Lone Star Industries, Pryor, Oklahoma

Lone Star Industries of Pryor, OK was issued a Notice of Violation on October 3, 1990. The Oklahoma State Department of Health found a sizable accumulation of baghouse waste dust on the property outside of the building. This accumulation of dust was in violation of the Oklahoma air pollution control regulation governing fugitive dust.

2.5 On-site Observations

In addition to documented cases of violations of air quality regulations for fugitive dust emissions, EPA also has received reports (in some cases including photographs) of and observed examples of particulate emissions of CKD from quarries, haul roads, and dust handling equipment. These observations are summarized below.

2.5.1 Public Concerns (Comments on the *Report to Congress*)

In response to its *Report to Congress on Cement Kiln Dust*, EPA received a number of comments from citizen groups and individuals regarding fugitive CKD emissions in areas adjacent to cement plants (EPA 1994). For example, a citizens' group in Texas commented that residents of Midlothian have observed, measured, and documented clouds of fugitive dust emissions, containing CKD, coming from pits at several area cement plants adjacent to residential and agricultural areas. A second Texas group cited a letter from the American Lung Association that states that "[t]here have been extensive problems at Lafarge [in New Braunfels and now owned by Texas Industries] of fugitive emissions from the handling, conveyance and disposal of CKD leading to community air pollution problems and enforcement actions." Some commenters expressed concern over inadequate dust control measures; one stated that fallout from quarry-dumps containing CKD can be significant for adjacent landowners in the absence of buffers between the dumps and residential, agricultural, and recreational land use areas. Another commenter suggested that all dust piles must be kept covered to prevent fugitive emissions, and one commenter expressed concern about those who handle CKD during the application to agricultural fields.

2.5.2 EPA Site Visits

Since beginning its study of the cement industry and CKD in 1991, EPA has visited more than 25 cement plants across the country. During several of these visits, the Agency has observed examples of fugitive dust emissions at disposal sites, along roads from trucks used to transport dust from the kiln to the final point of disposal, and outside of air pollution control devices (baghouses, electrostatic precipitators).

2.5.2.1 1992 and 1993 CKD Sampling and Analysis Program

EPA conducted a CKD and cement clinker sampling and analysis program in 1992 and 1993 as part of its data collection efforts for the *Report to Congress*. Over the two-year period, EPA visited 20 cement plants. In addition to clinker, EPA sampled CKD at the point of generation ("as generated" samples) as well as at the point of on-site disposal ("as managed" samples). In several cases, the Agency observed emissions of fugitive dust from CKD waste piles while collecting the "as managed" samples. These observations are documented in trip reports (EPA, 1992) that are available in the RCRA docket on the *Report to Congress* (Docket No. F-94-RCKA-FFFFF) and are summarized below.

- Essroc Materials, Speed, IN, March 16, 1992: EPA observed fugitive dust being swept from CKD piles during sampling; wind speed was estimated to be approximately 10 miles per hour (mph).

- Holnam, Inc., Clarksville, MO, April, 2, 1992: EPA observed large amounts of fugitive dust at the CKD disposal area during sampling. The Agency determined that the source of the dust was primarily the sifting operations near the pug mill and not emissions from the waste pile itself.

- Ash Grove Cement, Chanute, KS, April 3, 1992: Before beginning sampling at the facility's CKD monofill, EPA observed considerable fugitive dust emissions from a truck depositing CKD on the monofill. Facility representatives attributed the emissions to the loss of water pressure in the truck's dustless unloader. During sampling, fugitive dust from the sampled piles often obscured visibility; the sampling team estimated wind speeds at more than 20 mph.

- Independent Cement, Catskill, NY, April 6, 1992: EPA observed that some CKD would blow away when the surface of the CKD disposal pile was broken in order to collect unweathered dust samples.

- Dixie Cement, Knoxville, TN, April 9, 1992: EPA observed frequent dust emissions from the tops of piles in the CKD disposal area during sampling.

- Texas Industries, Midlothian, TX, April 10, 1992: While preparing equipment rinse blanks in the back of the sampling truck, EPA observed some fugitive dust in ambient air outside the truck. Wind speed was estimated to range between 10 and 20 mph.

2.5.2.2 Lafarge Corporation, Alpena, Michigan Site Video

Lafarge's Alpena, Michigan plant is the nation's largest cement manufacturing facility. Its five kilns have combined annual and daily clinker capacities of 1.92 million metric tons and 5,922 metric tons, respectively, as reported in 1994 (PCA 1995). EPA visited the plant in May, 1996 to update and augment its knowledge of CKD management practices. In addition, a local citizens' group provided the Agency with several video tapes of fugitive dust emissions from the site.

EPA visited the Lafarge facility to examine CKD disposal areas and practices at the plant. In addition, EPA sought to learn about facility operations, CKD generation and management practices, design of future CKD disposal areas, environmental monitoring practices (and, as available, results), and compliance with relevant federal and state laws (e.g., permit conditions). As part of the May 1996 site visit, EPA recorded CKD management practices on video tape.

The following observations were made based on the video-taped (Tape #1) management practices as part of the May 96 site visit:

> **Loading:** Tape # 1 shows wet pelletized CKD being loaded into a dump truck. It is evident that steam is being generated from the CKD in the truck. This is possibly a result of hydration reactions within the CKD or as a result of potentially elevated temperatures of the pelletized CKD compared to air temperatures. Although this material appears to be all steam, these are less than ideal conditions for observations because the steam could hide some fine particle emissions.
>
> **Transport:** Tape # 1 shows the same conditions occur during transport, although the emissions appear to be steam, some particulate emissions could be occurring. Some dust is evident from the truck tires as the trucks transport the pile to the disposal area.

The following observations are based on independent video footage, which consisted of three tapes (#'s 6, 11 and 12):

Loading: Tapes 6, 11 and 12 show a conveyor that carries the CKD directly to the disposal storage area. Here the release of CKD high above the ground leads to a lot of dispersion of the dust. At times, when the wind conditions are just right, the dispersion is so widespread that the entire conveyor system disappears from sight.

Transport: Tape #'s 6, 11 and 12 show the plumes of dust from both the uncovered truck-bed as well as the truck tires, as the trucks transport the pile to the disposal area. However, it is also observed that when the transport route was wetted sufficiently by a sprinkler, such fugitive emissions reduced dramatically from the tires and no emissions are evident when haul roads are sufficiently wetted. Wet CKD also reduced emissions from the truck-bed. This can be seen from both tapes 6 and 12.

Unloading: Just like the loading process, unloading releases tremendous amounts of dust into the atmosphere, especially under the right wind conditions. This is further aided by the high rate of dumping from the truck-beds themselves. Massive vertical dust clouds rising approximately 100 feet in the air result from the rapid dumping of CKD. In the disposal quarry shown in tapes 6, 11 and 12, dumping is carried out from the top of a huge CKD pile (formed by repeated bulldozing) into a valley. The CKD is blown around not only by the wind blowing along, or across the valley, but also by the downward momentum of the dumped CKD mass along the steep pile slopes.

Placement/compaction at the landfill: Both the bulldozing of the CKD into the landfill and the temporary storage piles at the disposal site are huge sources of fugitive dust emissions. This is captured very vividly in two dust "eruptions" (Tapes 6 and 11) on the pile slopes (or CKD dunes), due to sudden gusts of wind in the quarry. This is a chain event, triggering further agitation of dust in the path of the dust cloud. The right wind conditions can quickly spread this dust over a huge area as can be seen in Tapes 6 and 11.

Water: Other problems include the dust depositing and transporting CKD contaminants onto runs, and culverts (adjacent to the quarry) emptying into lake Huron. The stream/culvert water is varied in color, murky at most times, with a lot of scum, or oil on the surface at times (Tapes 6 and 12). This contaminated runoff discharges directly into the lake. This can have a detrimental effect on aquatic life in the lake - for instance, the commentator shows a dead fish with badly burnt tissue that was found floating on the lake, close to the runoff .

Effects on humans: According to the commentator, the smell is carried into nearby towns when the wind changes direction. Dust can be seen from the town located at least a mile from the plant (Tapes 6 ad 12).

> The commentator makes the following observations: The dust itself is very irritating to the throat and causes coughing. The sometimes very turbulent conditions combine with the dry disposal storage piles and produce near zero visibility. Sometimes, dust storm-like conditions are produced due to large disturbances. Homes located close to the site (a mile or so away), receive a daily coat of fine dust on car wind-shields and home window-panes that are reported to have to be cleaned daily (Tape 12). Although some of this dust is likely to come from stack emissions, transfer of fugitive CKD across property lines in visible quantities is evident.

2.6 Population Effects from Exposure to Airborne CKD

Following the Regulatory Determination, EPA calculated population risks for individuals living in the vicinity of cement manufacturing plants that manage CKD onsite. The assessment included population risks from indirect, or foodchain, exposure pathways and population effects from exposure to airborne particles. A detailed description of the population risk assessment is provided in the *Technical Background Document: Population Risks from Indirect Exposure Pathways, and Population Effects from Exposure to Airborne Particles from Cement Kiln Dust Waste* in the docket for this rule (EPA 1997).

Chapter 3: Identification and Evaluation of Options for Technical Design Standard

This chapter examines air emissions of CKD from waste management activities, techniques for controlling such emissions, and the effectivenss of these control techniques. To estimate air emissions of CKD and the emission reductions that may be realized by applying selected control technologies, EPA evaluated the technologies as they would be applied at two cement manufacturing facilities, Facility A and Facility B. The Agency chose these facilities because they are considered to be (1) a representative drier climate, potentially high-emissions facility (Facility A) and (2) a representative wetter climate, potentially low-emissions facility (Facility B), based on a review of previous modeling results of airborne particulate concentrations (EPA 1994). Exhibit 3-1 presents the input data parameters assumed for each facility. (These parameter values are consistent with the values used for these facilities in the Agency's risk analysis of particulate matter.) The facilities dispose different amounts of CKD, with Facility A disposing 67,438 tons of CKD and Facility B disposing 907 tons of CKD in 1990 (PCA Survey 1991).

3.1 Emissions Estimation

3.1.1 Description of CKD Handling Processes at the Sample Facilities

At Facility A, CKD from the electrostatic precipitator is collected in a storage tank that is essentially closed. From the tank, the CKD is pelletized with water during the transfer process before being loaded into a transport truck. The truck then transports the CKD to the disposal site, where it is placed in temporary piles. Periodically, the temporary piles are leveled by bulldozing. Since two of the control options under consideration for this analysis are pelletization and addition of water to storage piles, EPA assumed dry, unpelletized CKD for estimating baseline emissions for Facility A's CKD handling train in order to examine the emission reductions achievable through water addition and pelletization for a facility of this size.

At Facility B, CKD is first stored in an temporary storage pile located near the facility. The CKD is then periodically loaded into trucks using a front-end loader; no wetting occurs in this process. After loading, the trucks transport the CKD to the final pile. There is no temporary storage at the disposal site.

Exhibit 3-1
Input Data Used to Estimate Emissions from CKD Handling Train

Parameter	Site Facility B	 Facility A	Comments
Exposed area of landfill (m^2)	10,219	8,733	Site-specific, based on facility responses to the *PCA Cement Kiln Dust Survey* (1991) and best engineering judgement and observations made during EPA's site visit in 1992
Percent of landfill area disturbed each time CKD is dumped (%)	20	30	Site-specific, based on best engineering judgement and observations made during EPA's site visit in 1992
Moisture content of CKD in handling train (%)	0.25	0.25	Selected as the smallest value possible (closest to zero) within the range of validity for the emissions equation
Number of days with > 0.01' of rain	115	79	From closest meteorological station
Mean wind speed (m/s)	4.58	4.31	From closest meteorological station
Fastest mile (m/s)	22.2	26	From "Extreme Wind Speed at 129 Stations in the Contiguous United States"(values used for previous exposure modeling)
Threshold friction velocity (m/s)	0.25	0.25	Estimated based on graphical relationship of threshold friction velocity to CKD size distribution mode (Gillette, 1980)
Silt content of unpaved road surface (%)	20	20	Default assumption (no site-specific data provided) near upper end of range reported in literature for industrial sites (Cowherd *et al.*, 1985)
Silt content of CKD (%)	90	90	Estimated based on weight fraction of CKD less than 75 µm (obtained from literature)
Mean weight of vehicle (tons)	52	52	Gross weight of a 25-ton capacity truck
Mean number of wheels	10	10	Best engineering judgement and field observations
Length of road in miles (one way)	0.25	0.6	Site-specific, based on facility maps and site visits
Number of vehicle round trips/day	0.2	16	Calculated based on daily disposal rate (see below)
Vehicle miles traveled (VMT)/day	0.1	19.2	Calculated based on length of road and number of round trips/day
Mean vehicle speed (mph)	20	20	Best engineering judgement based on site observations
Number of working days/year	340	339	*PCA Cement Kiln Dust Survey* (1991)
Annual CKD disposal rate (tons)	907	67,438	*PCA Cement Kiln Dust Survey* (1991)
Daily CKD disposal rate (tons/operating day)	2.7	198.9	Calculated from annual disposal rate and number of working days/year

3.1.2 Description of Methodology

EPA estimated emissions using methods and equations from its *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources, Fifth Edition* (commonly referred to as *AP-42*); much of the following discussion is extracted from this document. The methods presented in *AP-42* for estimating fugitive dust emissions are principally compiled from *Control of Open Fugitive Dust Sources* by Cowherd et. al. (1988), which was used as a supplemental reference. *AP-42* contains the emission estimation methods and equations recommended for use by EPA's Office of Air Quality Planning and Standards. EPA believes that it provides the best approach available, short of conducting new field studies to measure emissions.

As noted in *AP-42*, significant atmospheric dust arises from the mechanical disturbance of granular material exposed to the air. Dust generated from these open sources is termed "fugitive" because it could not reasonably pass through a stack, chimney, vent or other functionally equivalent opening. As previously described, common sources of fugitive dust include wind erosion from CKD piles, CKD handling (e.g., loading and unloading), unpaved road travel, and bulldozing of CKD. For these sources, the dust-generation process is caused by two basic physical phenomena:

4. Entrainment of dust particles by the action of turbulent air currents, such as wind erosion of an exposed surface; and

5. Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.), as usually occurs during CKD handling.

3.1.2.1 Estimating Emissions from Wind Erosion

EPA estimated emissions from wind erosion of exposed surfaces using the procedures outlined in *AP-42*, Section 13.2.5, for the temporary storage piles and the area of the landfill disturbed during each loadout of CKD. These procedures are based on the following assumptions:

1. The uncovered surface of the dust pile or landfill is characterized by a finite availability of erodible material, referred to as the erosion potential;

2. Particulate emission rates tend to decay rapidly (i.e., with a half life of a few minutes) during an erosion event; and

3. Emissions can be related to the erosion potential of the surface.

A single gust of wind can quickly deplete a substantial portion of the erosion potential, and the erosion potential will not be restored until the surface is subsequently disturbed.

Erosion potential is calculated based on the fastest wind speed during the period between disturbances and the threshold friction velocity of the material. (The friction velocity is the measure of wind shear stress on the erodible surface; the friction velocity must exceed the threshold friction velocity of the material for wind erosion to occur.) Since the erosion potential of a surface is restored each time the surface is disturbed, emissions for a specified time period are also dependent on the number of disturbances occurring within that period. Any natural crusting of the surface, such as that which has been observed in the field for weathered CKD, binds the erodible material and thus reduces the erosion potential. Exhibit 3-2 lists the *AP-42* variables and equations that EPA used to estimate erosion potential for storage piles and disposal sites at the two facilities. It is important to note that the equations presented in *AP-42* for estimating wind erosion represent intermittent events, rather than steady-state emissions. The Agency used the "fastest mile" data from "Extreme Wind Speed at 129 Stations in the Contiguous United States" to calculate emissions for this analysis. This wind speed represents the mean annual fastest mile. (Analysis of historical meteorological data to determine mean daily fastest mile values for each facility and the subsequent use of these values to estimate emissions were beyond the scope of this effort.) Consequently, EPA calculated the emission estimates prepared for this analysis by assuming that the mean annual fastest mile occurs between every disturbance (i.e., as frequently as once per day) instead of once per year, and thus may overstate actual emission rates.

Threshold friction velocity data for CKD were not available from literature or site-specific data. It is likely that additional field studies and/or wind tunnel measurements would be required to adequately quantify this parameter, as previous work in the field has not focused on collecting physical data needed to characterize air emissions of CKD. Absent such data for CKD, EPA estimated the threshold friction velocity based on a graphical relationship developed by Gillette et. al. (1980) between threshold friction velocity and the size of the aggregate distribution mode (see Figure 3-1). Because CKD is predominantly less than 75 micrometers (µm) in diameter (see Exhibit 2-1), the threshold friction velocity for the smallest distribution mode included on the graph (0.1 mm or 100 µm) was selected. Since the behavior of the function outside of the reported data range was unknown, the Agency made no attempt to extrapolate the threshold friction velocity for a smaller size distribution mode. The resulting threshold friction velocity, 0.25 meters per second (m/s), is approximately half of the value reported in *AP-42* for fine coal dust on a concrete pad (0.54 m/s). The actual threshold friction velocity of dry CKD may be smaller than the assumed value due to the extremely fine particle size of CKD. However, the natural tendency of CKD to crust when exposed to moisture will tend to increase the threshold friction velocity for weathered surfaces by an unknown amount.

Exhibit 3-2
Variables and Equations Used to Estimate Emissions from Wind Erosion

Variable	Description	Method of Determination/Calculation
u^{+}	Fastest mile value (m/s) at an anemometer height of z meters	Obtained from meteorological data
u_{10}^{+}	Fastest mile value (m/s) converted to a referenced height of 10 meters	$u_{10}^{+} = u^{+} \dfrac{1n\ (10/0.005)}{1n\ (z/0.005)}$
$\dfrac{(u_s)}{(u_r)}$	Ratio of surface wind speed (u_s) to approach wind speed (u_r)	Determined from AP-42 Figure 13.2.5-2 based on pile geometry and wind flow direction
u_s^{+}	Surface wind speed (m/s) corresponding to the fastest mile	$u_s^{+} = u_{10}^{+} \dfrac{(u_s)}{(u_r)}$
u^{*}	Equivalent friction velocity (m/s) for piles which significantly penetrate the surface wind layer (height-to-base ratio exceeding 0.2) (used to estimate erosion from storage piles)	$u^{*} = \dfrac{(0.4\ u_s^{+})}{\left(\dfrac{25}{1n(0.5)}\right)} = 0.10\ u_s^{+}$
u*	Equivalent friction velocity for large, relatively flat piles or exposed areas with little penetration into the surface wind area (used to estimate erosion from landfill)	$u^{*} = 0.053\ u_{10}^{+}$
u_t^{*}	Threshold friction velocity (m/s)	Obtained from field measurements of the mode of the aggregate size distribution, from graphical relationship by Gillette (see Figure 1), or from reported values in AP-42 for selected materials
P	Erosion potential (g/m^2)	$P = 58\ (u^{*} - u_t^{*})^2 + 25\ (u^{*} - u_t^{*})$ $P = 0 \text{ for } u^{*} \quad u_t^{*}$
N	Number of disturbances/year	Site-specific
k	Particle size multiplier (dimensionless)	k = 1.0 for PM_{30} = 0.5 for PM_{10} = 0.2 for $PM_{2.5}$
EF	Emission factor (g/m^2-yr)	$EF = k \sum_{i=1}^{N} P_1$

Note: These are standard methods employed in AP-42.

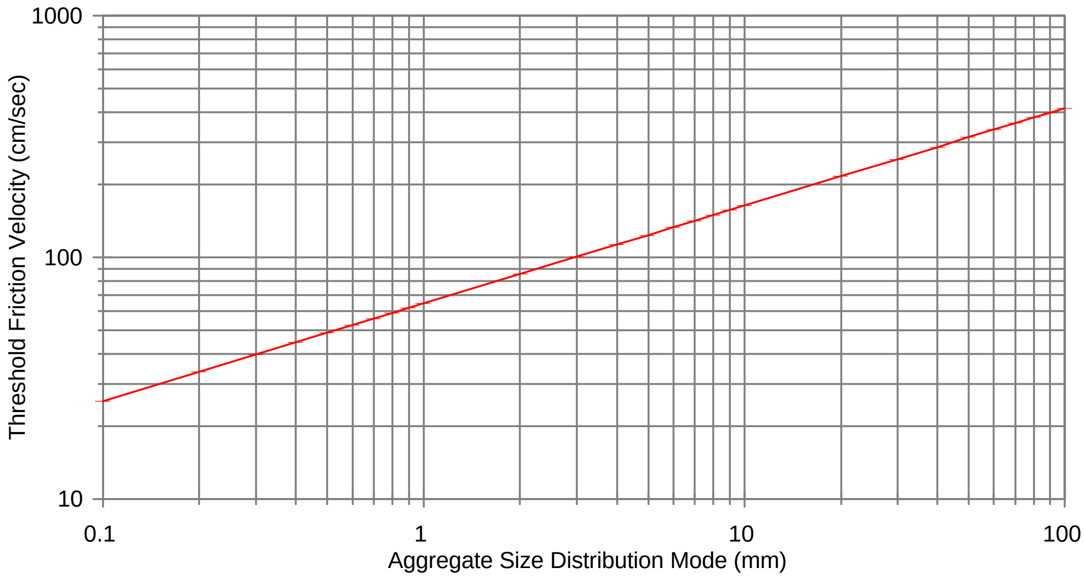

Figure 3-1: Gillette relationship of threshold friction velocity to size distribution mode (source: *Control of Open Fugitive Dust Sources*, EPA, 1988).

To estimated emission rates, EPA assumed storage piles to be conical in shape and equal in volume to one truck load (assumed to be 10 cubic yards [yd^3]), with a height equal to two-thirds the base diameter. Due to the geometry of a conical storage pile, EPA divided the surface area of the pile into four separate regimes, each characterized by a different ratio of surface wind speed to approach wind speed. The Agency estimated the erosion potential for each subarea of the pile separately and summed over all subareas to yield the total erosion potential for the pile. This procedure, which is standard practice in fugitive dust modeling, is described in Section 13.2.5 of *AP-42*. In addition, due to the relatively small quantity of CKD produced by Facility B (2.3 yd^3/day), the Agency assumed that the temporary storage pile accumulates over a period of five days (i.e., until approximately one full truck load has accumulated) prior to removal of the pile and transport to the landfill.

3.1.2.2 Estimating Emissions from CKD Handling

EPA estimated dust emissions from several distinct handling activities, including loading of CKD onto storage piles and loadout of CKD to trucks and from trucks to the landfill. The Agency estimated these emissions using the following empirical relationship from *AP-42 (Section 13.2.4, Aggregate Handling and Storage Piles)*:

$$E = 0.0032k \frac{\left(\frac{U}{5}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}}$$

where

E = emission factor (lb/ton);
k = particle size multiplier (dimensionless);
U = mean wind speed (mph); and
M = moisture content of material (%).

The particle size multiplier, k, varies with aerodynamic particle size range; the values given for k for this equation in *AP-42* are 0.74 for PM_{30}, 0.35 for PM_{10}, and 0.11 for $PM_{2.5}$. Note that values for k are usually determined from field studies, and that recommended k values for different equations and empirical correlations will differ (e.g., the k value for the wind erosion calculations differ from these k values). Further, EPA notes that the silt content is outside the range of the source conditions used to develop the above equation. As a result, *AP-42* recommends that the quality rating of the emissions estimates be reduced from “excellent” to “above average.”[2]

EPA applied this equation each time the CKD was handled. For Facility B, EPA assumed three handling operations for a given quantity of CKD: (1) loading onto the temporary storage pile at the facility; (2) loading from the temporary storage pile into the truck for transport to the landfill; and (3) loadout from the truck into the landfill. Because Facility A does not have a temporary storage pile at the facility (CKD is transferred from an enclosed storage tank directly to the truck), the Agency assumed only the latter two handling operations.

3.1.2.3 Estimating Emissions from Unpaved Road Travel

EPA estimated emissions from unpaved road travel for trucks transporting CKD to the disposal site and returning to the facility using the following equation from Section 13.2.2 of *AP-42*:

$$E = 0.59k \left(\frac{s}{12}\right) \left(\frac{S}{30}\right) \left(\frac{W}{3}\right)^{0.7} \left(\frac{w}{4}\right)^{0.5} \left(\frac{365 - p}{365}\right)$$

---

[2] *AP-42* assigns an “excellent” quality rating to emission factors when they are based on test data developed with a sound methodology from many randomly chosen facilities and the source category population is sufficiently specific to minimize variability. An “above average” rating is assigned when the test data are from a “reasonable number” of facilities, such that no specific bias is evident but it is not clear if the data are from a random sample.

where

E = emission factor (lb/VMT);
k = particle size multiplier; equals 1.0 for PM_{30}, 0.36 for PM_{10}, and 0.095 for $PM_{2.5}$ (dimensionless);
s = silt content of road surface material (%);
S = mean vehicle speed (mph);
W = mean vehicle weight (tons);
w = mean number of wheels; and
p = number of days per year with at least 0.01 inches of precipitation.

The resulting emission factor was then multiplied by the vehicle miles traveled (VMT) to estimate emissions. The Agency estimated vehicle miles traveled for each facility based on the road distance between the facility and the disposal site, and the number of trips per day required to dispose of the amount of CKD generated daily, assuming a truck capacity of 10 yd^3 of CKD. Due to the relatively small amount of CKD generated at Facility B (2.7 yd^3/day), EPA assumed one trip every five days for this facility.

3.1.2.4 Estimating Emissions from Bulldozing

The Agency estimated emission factors from bulldozing of the temporary CKD storage piles at Facility A using the following equations for bulldozing of overburden from Table 11.9-2 of *AP-42*:

$$E_{PM_{30}} = 5.7 \frac{(s)^{1.2}}{(M)^{1.3}}$$

$$E_{PM_{10}} = 0.75 \frac{(s)^{1.5}}{(M)^{1.4}}$$

$$E_{PM_{2.5}} = 0.105 \; E_{PM_{30}}$$

where

$E_{PM_{30}}$ = emission factor (lb/ton) for PM_{30};
$E_{PM_{10}}$ = emission factor (lb/ton) for PM_{10};
$E_{PM_{2.5}}$ = emission factor (lb/ton) for $PM_{2.5}$;
s = silt content of material (%); and
M = moisture content of material (%).

EPA estimated the silt content of CKD to be 90 percent, based on the weight fraction of particles less than 75 µm (from Dust "G" from the article "Cement Kiln Dust Management: Permeability," Todres *et al.*, Portland Cement Association, 1992). Since the CKD is allowed to weather prior to bulldozing, EPA assumed that the moisture content increased from 0.25 percent (dry CKD from the kiln) to 1 percent in the temporary storage piles prior to bulldozing. The emission factors were then multiplied by the annual and daily CKD disposal rates to estimate total emissions.

3.1.3 Uncontrolled Emissions Estimates

Using the methods and equations described in Section 3.1.2, EPA developed uncontrolled annual and average working day emission rates for the two facilities; these are presented in Exhibit 3-3.

3.2 Fugitive Dust Control Techniques for Temporary Storage, Transport, and Disposal

This section describes the techniques EPA considered and evaluated for controlling fugitive dust at each of the points in the CKD management process.

3.2.1 Description of Dust Generation and Handling

There are several points in the CKD management process at which fugitive dust controls can be applied. While not every facility manages dust in exactly the same manner, a typical management sequence may include:

Temporary storage at the facility,
Transport of CKD from the plant to the landfill area, and
Disposal activities at the landfill.

Each of the technologies considered for meeting the performance design standard for controlling fugitive dust emissions at these points is discussed in more detail below.

3.2.2 Management at Temporary Storage Point at the Plant

Technologies considered for controlling fugitive dust emissions at the temporary storage point at the facility include enclosures, covers, pelletization of the dust, and adding water to the surface of the pile.

Exhibit 3-3
Uncontrolled Emission Estimates

	Facility B			Facility A		
	PM_{30}	**PM_{10}**	**$PM_{2.5}$**	**PM_{30}**	**PM_{10}**	**$PM_{2.5}$**
Emissions (lb/year)						
Temporary Storage at facility	771	386	154	NA	NA	NA
Aggregate Handling	301	142	45	13,783	6,519	2,049
Transport - unpaved road	1,531	689	182	335,345	150,905	39,822
Transport - entrainment from truck	124	62	25	12,747	6,373	2,549
Temporary Piles at Disposal Site	NA	NA	NA	14,569	7,284	2,914
Bulldoze Temporary Storage Piles	NA	NA	NA	85,074,685	43,177,700	8,932,842
Disposal Site - Disturbed Area	24,767	12,383	4,953	22,0943	110,472	44,189
Total	27,494	13,662	5,359	85,672,071	43,459,254	9,024,365
Emissions (lb/average working day)						
Temporary Storage at facility	2.3	1.1	0.5	NA.	NA	NA
Aggregate Handling	0.9	0.4	0.1	40.7	19.2	6.0
Transport - unpaved road	4.5	2.0	0.5	989.2	445.1	1,17.5
Transport - entrainment from truck	0.4	0.2	0.1	37.6	18.8	7.5
Temporary Piles at Disposal Site	NA	NA	NA	43.0	21.5	8.6
Bulldoze Temporary Storage Piles	NA	NA	NA	250,957.8	127,367.8	26,350.6
Disposal Site - Disturbed Area	72.8	36.4	14.6	651.7	325.9	130.3
Total	81	40	16	252,720	128,198	26,621
Percent of Total Emissions						
Temporary Storage at facility	2.81	2.82	2.88	NA	NA	NA
Aggregate Handling	1.09	1.04	0.83	0.02	0.02	0.02
Transport - unpaved road	5.57	5.04	3.39	0.39	0.35	0.44
Transport - entrainment from truck	0.45	0.45	0.46	0.01	0.01	0.03
Temporary Piles at Disposal Site	NA	NA	NA	0.02	0.02	0.03
Bulldoze Temporary Storage Piles	NA	NA	NA	99.30	99.35	98.99
Disposal Site - Disturbed Area	90.08	90.64	92.43	0.26	0.25	0.49
Total	100.00	100.00	100.00	100.00	100.00	100.00

NA = not applicable (the source does not exist at that facility).

3.2.2.1 Enclosures

Enclosures include silos as well as warehouse-type structures and dome-shaped buildings such as those used by transportation agencies to store road chemicals (e.g., salt and sand). These buildings do not have to conform to full RCRA Subtitle C containment standards, but should have a roof, floor, and walls. These structures reduce emissions by removing the CKD from the environment, thus eliminating exposure to wind and subsequent dispersal.

3.2.2.2 Covers on Piles

Examples of covers on temporary storage piles include adding a layer of soil (loam) to the top of the pile or spraying a latex binder on the top of the pile. Adding a layer of soil over the top of the pile will reduce emissions, because the soil is less erodible; that is, the soil is more likely to clump together and less likely to be blown away. The latex binder reduces emissions in a similar manner, by causing the CKD to form a crust, thereby reducing the erodibility of the CKD.

3.2.2.3 Pelletization

Pelletization is a control technology that might first be applied at an temporary storage point; however, it is likely to help reduce emissions during transport and at temporary storage piles as well. Pelletization is currently used both to aid in recycling CKD and to prepare CKD for disposal (EPA 1993). CKD is formed into small spherical pellets by passing it through paired rollers with recessed surfaces. These pellets have much more cohesion than loose CKD, and are therefore less susceptible to wind erosion. (Pellets can also be formed by rolling CKD in a drum or inclined disk with water; however, pellets made this way are more likely to break up.) Depending on the strength of the pellets, pelletization may even reduce emissions at the landfill, if the pellets are strong enough to maintain their cohesive properties. Drying and excessive mechanical damage to pellets can reduce or eliminate the effectiveness of this technique in controlling fugitive emissions.

3.2.2.4 Water Addition

Water addition may be used to suppress fugitive dust emissions at temporary storage piles. Application of water to piles of CKD promotes formation of a crust that will decrease emission of dust (by increasing the threshold frictional velocity; see discussion in section 3.1.2.1 above) from the temporary storage pile. For this technology, a facility is assumed to apply water to the pile using a hose and nozzle. Application rates vary depending upon climatological factors, especially rainfall, relative humidity, evaporation rate, and wind speeds at the temporary pile.

3.2.3 Management of Transport of CKD from Plant to Landfill

Appropriate techniques for controlling fugitive dust along the haul road from the plant to the disposal area include adding water to the road surface, covering the dust in the bed of the truck, and/or cleaning the bed of the truck after dust is unloaded at the disposal area. These techniques are summarized below.

3.2.3.1 Water Addition to Unpaved Road Surface

Applying water to unpaved roads is known to be effective in mitigating fugitive dust emission at industrial and construction sites. At most cement manufacturing facilities, at least a part of the route traveled by CKD haul trucks is unpaved. These unpaved roads also are used by trucks transporting raw materials to the cement plant. Regular water addition to unpaved roads suppresses dust emission and prevents the carryout of fugitive CKD by the truck traffic. (“Carryout” refers to the dispersion of dust on paved and unpaved roads caused by vehicular traffic.) The control efficiency of water addition to unpaved roads depends upon the following key variables: (1) traffic volume; (2) climatological conditions (especially rainfall, humidity, wind sprred, evaporation); (3) application rates for water; and (4) elapsed time between water applications.

3.2.3.2 Pelletization and Water Addition to Trucked CKD

Addition of water to CKD prior to transport in trucks will reduce fugitive emissions. The amount of water added to CKD will vary between sites and climatic areas of the country. Addition of greater than about 50 percent water to CKD results in producing a slurry. Slurries will generally be piped (rather than trucked) to the disposal site. Pelletization involves addition of about 10 percent water to CKD. Wet compaction is generally described as wetter than pelletized CKD, but not as wet as a slurry. Wet compaction is assumed to require about 30 percent water addition. This type of wetting of CKD prior to transport may be as effective for control at some facilities as covering of trucks carrying dry CKD.

3.2.3.3 Covers on Trucks

To prevent air entrainment and spillage during hauling, CKD must be transported in trucks with adequate freeboard and cover. (“Freeboard” is the distance between the top of material stored in a truck bed and the rim of the bed’s walls.) Typically, these covers are tarps or screening material that is extended over the truck’s bed and secured. At least one state (Michigan) has defined “completely covering open-bodied trucks” as a requirement of fugitive dust emission control programs. The construction industry is required to follow the practice of covering dump trucks in some cases (e.g., when hauling hotmix asphalt, construction debris, etc.). Several manufacturers supply roll-on tarp systems for covering bulk materials transported by trucks. Alternatively, tarps can be tied down manually after the truck has been loaded.

3.2.3.4 Cleaning of Trucks and Covers After Each Load

In addition to transporting CKD in trucks with covers, the trucks themselves may be cleaned after unloading CKD at the disposal area. Cleaning these trucks can help reduce air emissions on the return trip and prevents the buildup of excessive dust in and on the trucks over time. Operationally, this involves vacuuming all surfaces of the truck that were in contact with the CKD being hauled and, as an added measure, replacing the truck cover with a cleaned one after each hauling trip.

3.2.4 Management of CKDLF Units

Techniques for controlling dust emissions from a CKD landfill unit (CKDLF) include (1) wetting and pelletizing the dust before disposal, (2) wet compaction of CKD, and (3) adding water, soil, or a chemical covering such as latex to the pile.

3.2.4.1 Pelletization

As described above, pelletization is a material management method in which finely divided particulate material is compressed through paired rollers with recessed surfaces so that the particles cling together and form small, spherical pellets. In the current context, pelletization also can be accomplished by rolling CKD in a drum or inclined disk with water; however, pellets made this way are more likely to break up. A typical pelletization system will consist of a pelletizer, which includes a feed hopper, a chute feeding the roller pair, a roller pair, and a chute to convey the pellets away from the roller.

3.2.4.2 Wet Compaction/Conditioning

The process of wet compaction involves adding water to the CKD prior to load-out to get a clotted material with a wet consistency. Although wet compaction management scenarios may vary by facility, the material will generally be similar to or wetter than pelletized CKD and drier than a slurry. The moisture content for wet compaction is assumed to be between 10 and 50 per cent. This wet material is then transferred to the landfill and dumped. The method of transport is assumed to be in a truck similar to pelletized CKD. At the disposal site, the wet CKD is compacted into layers by the use of either rollers or other heavy equipment driving over the material.

This compacted wet material is reported to bind and form a fairly solid material. This solid material is reported to be similar to a low-grade cement and will remain in a fairly solid form until mechanically disturbed. Although some flaking or scaling may occur that may produce fugitive dust from undisturbed compacted CKD, when subjected to mechanical action the dry material is easily crushed and once again prone to substantial fugitive emissions. For this reason, wet compaction must be part of an overall management practice that includes covering and protection from mechanical disturbance once it is dry. The emissions from wet compacted CKD once it is covered are assumed to be zero.

3.2.4.3 Water Addition

Adding water to CKD at the landfill is used to suppress dust emissions following placement in a disposal unit. Water addition controls dust emissions by causing the fine particles of dust to agglomerate and bind to the aggregate surface, preventing them from becoming suspended in air. The degree of agglomeration depends on the amount of material covered and on the ability of the liquid to wet small particles.

For this control technique, a facility is assumed to pump available on-site water to the landfill via piping, and spray the water over the disturbed portion of the landfill each day CKD is placed in the landfill. In reality, the frequency of application will depend on climatological factors such as humidity, evaporation rate, wind speed, and rainfall. Also, water addition cannot be used when temperatures fall below freezing. More effective wetting can be achieved by reducing the diameter of the water droplets and increasing their number through appropriate selection of pumps and nozzles used for the water spraying system. Surfactants also may be used with water sprays to improve the wetting of materials.

3.2.4.4 Chemical Addition

Chemical addition to CKD at the landfill is used to suppress dust emissions following placement in a disposal unit. Chemical addition controls dust emissions by causing the fine particles of dust to agglomerate and bind to the aggregate surface, preventing them from becoming suspended in air. The degree of agglomeration depends on the amount of material covered and on the ability of the liquid to wet small particles. For this control technique, a facility would mix the chemical binder (e.g., latex) with water, and spray the solution over the landfill.

3.2.4.5 Covering Conditioned CKD Lifts

Conditioned CKD forms a solid material similar to a low-grade cement. As mentioned in the discussion of wet compaction, this material has the potential to be a source of fugitive emissions if not properly managed. Drying, scaling and mechanical disturbance can combine to break conditioned CKD down to produce fine particles that can once again become airborne fugitive dusts. This can be prevented by covering the conditioned CKD with materials (e.g., latex additives, soil) of sufficient strength, thickness, chemical and physical properties to prevent contact with the conditioned CKD. Appropriate selection of cover materials should be done on a site specific basis.

3.3 Control Efficiencies for Fugitive Dust Control Technologies

This section describes the estimation of control efficiencies for the fugitive dust control technologies considered. The primary sources of information and equations used as a basis for estimating the efficiency of each control are described in detail below.

In conducting research on CKD and the cement manufacturing industry for the past several years, especially in support of the *Report to Congress*, EPA conducted extensive literature searches on CKD and potential fugitive dust control options. Since these initial searches were conducted, subsequent literature searches and interviews with experts reveal that little new material has been published on fugitive dust emissions and controls, particularly regarding fugitive CKD at the disposal area. Cowherd (and Muleski and Kinsey) at Midwest Research Institute (MRI) are the primary authors of most of the available fugitive dust control technology information. Even recent publications on fugitive dust tend to focus on manufacturing processes, rather than bulk material handling and disposal operations. Even with the recent proposal of the new $PM_{2.5}$ National Ambient Air Quality Standards (NAAQS), new data regarding control technologies are limited because EPA's focus for the NAAQS revision has been on the health effects of $PM_{2.5}$ and not the potential control requirements, anticipated level of reductions, and the associated costs. Consequently, for this proposal, EPA based most of its analysis related to CKD on the MRI documents and other literature for which MRI provided input; the Agency supplemented this information with phone calls to control technology vendors and state regulators (for a few technologies) and other documents discussing fugitive dust in general. For many of the technologies, EPA relied upon its knowledge of cement facility operations and air emissions, especially fugitive dust and the associated control technologies, to develop control efficiencies using their best engineering and professional judgement.

3.3.1 Pelletization

EPA estimated the control efficiency for pelletization by considering two factors:

1. The change in the threshold friction velocity due to the increase in effective particle size; and

2. The increase in moisture content due to the addition of water during the pelletization process.

In the article “Pelletizing Waste Cement Kiln Dust for More Efficient Recycling”, Sell and Fischbach (1978) examined two sizes of oval pellets which were prepared with commercial pelletizing equipment: 1/4” x 3/8” x ½”, and 5/8” x ½” x 1”. Throughout the literature review summarized above, the Agency found no other or more current information on the size of pellets from commercial pelletizers. This review includes conversations with pelletizer vendors.

In order to estimate the impact of threshold friction velocity, EPA converted the smallest dimension listed in the article to millimeters, giving an approximate pellet diameter of 6.35 mm. The Agency then used the graphical relationship developed by Gillette et. al. (refer to Figure 3-1) to estimate a threshold friction velocity of approximately 1.3 m/s for an aggregate size distribution mode of 6 mm. EPA substituted this value for the CKD threshold friction velocity in the wind erosion calculations for temporary storage piles, resulting in a 92 percent reduction in emissions due to pelletizing (assuming minimal breakage of pellets).

For estimating reduced emissions from pelletization at the disturbed areas of the landfill, EPA performed a similar calculation. For the disturbed areas, however, the Agency assumed considerable pellet breakage due to driving over the material with the CKD haul trucks. EPA simulated the effects of breakage by assuming a reduced size distribution mode of 1 mm, corresponding to a threshold friction velocity of approximately 0.65 m/s. The resulting control efficiencies for pelletization at the landfill were 50 percent for Facility A and 57 percent for Facility B, accounting for the fraction of the surface area that is disturbed during dumping operations and the frequency of disturbance. The higher control efficiency estimated for Facility B results from the greater amount of time assumed between disturbances for this facility.

For handling and bulldozing of pelletized material, EPA assumed a moisture content of 10 percent for pelletized CKD in order to estimate the reduction in emissions. This value represents the lower end of the range reported by personnel at a sample of facilities that use pelletizers (interviewed over the phone or in person during site visits) and, thus, actual control efficiencies would likely be greater than evaluated efficiencies assuming minimal breakage of pellets. The resulting control efficiencies were 95 percent for PM_{30} and $PM_{2.5}$, and 96 percent for PM_{10}.

3.3.2 Water Addition for Storage Piles/Landfills

Wind erosion emissions are known to be strongly correlated with the inverse square of the moisture content, so EPA used the following relationship from *Control of Open Fugitive Dust Sources* (Cowherd *et al.*, 1988) to relate controlled and uncontrolled emissions with controlled and uncontrolled moisture content:

$$E_c = E_u \frac{(M_u)^2}{(M_c)^2}$$

where

E_c = controlled emission rate;
E_u = uncontrolled emission rate;
M_c = controlled moisture content (%); and
M_u = uncontrolled moisture content (%).

Accordingly, for a given control efficiency, EPA calculated the ratio of uncontrolled moisture content to controlled moisture content as shown in Exhibit 3-4. Note that doubling the moisture content resulted in a 75 percent reduction in emissions. This corresponds well with the control efficiencies predicted by another relationship presented in *Control of Open Fugitive Dust Sources* (Cowherd *et al.*, 1988) for watering of unpaved road surfaces, in which the instantaneous control efficiency was related to the ratio of controlled to uncontrolled surface moisture content according to the following bilinear relationship:

$$\begin{aligned} CE &= 75(M-1) \qquad \textit{for}\ 1 \quad M \quad 2 \\ CE &= 62+6.7M \qquad \textit{for}\ 2 \quad M \quad 5 \end{aligned}$$

where

CE = control efficiency (%), and
M = ratio of controlled to uncontrolled moisture content (equal to M_c/M_u).

This relationship predicts that between one and two times the average uncontrolled moisture content (a small increase in moisture content) yields a large increase in control efficiency. Beyond this point, control efficiency increases more slowly with moisture content.

For any particular situation, the required water application rate will be dictated by the desired control efficiency. Based on the above, a 75 percent reduction in emissions appears readily achievable. For this analysis, EPA assumed a low-end control efficiency of 55 percent corresponding to a 50 percent increase in moisture content and a high-end control efficiency of 75 percent corresponding to a doubling of moisture content because these appeared achievable. Higher control efficiencies (e.g., 90 percent) should also be achievable, but would require doubling of the moisture content.

Exhibit 3-4
Estimated Moisture Content Ratios for Various Control Efficiencies

CE	M_c/M_u	CE	M_c/M_u
10%	1.05	70%	1.83
20%	1.12	75%	2.00
30%	1.20	80%	2.24
40%	1.29	85%	2.58
50%	1.41	90%	3.16
60%	1.58	95%	4.47
65%	1.69	99%	10.00

M_c = controlled moisture content (%)
M_u = uncontrolled moisture content (%)
CE = control efficiency

3.3.3 Water Addition for Roadways

EPA estimated the control efficiency for water addition to unpaved roads using the following relationship from the *Air Pollution Engineering Manual* (Buonicore and Davis, 1992):

$$CE = 100 - \frac{0.8\ pdt}{i}$$

where

CE = average control efficiency (%);
p = potential average hourly daytime evaporation rate (mm/hr);
d = average hourly daytime traffic rate (hr^{-1});
i = application intensity (liters per square meter [L/m^2]); and
t = time between applications (hr).

The Agency estimated the potential average hourly daytime evaporation rate in mm/hr, which varies from site to site, by multiplying the mean annual Class A Pan Evaporation (in inches) by 0.0049 for annual conditions and by 0.0065 for summer conditions. The mean annual Class A Pan Evaporation for various areas of the US can be read from the isopleth diagram presented as Figure 4 of Chapter 4 of the *Air Pollution Engineering Manual*. The resulting potential average hourly daytime evaporation rates for the locations of Facilities A and B are shown in Exhibit 3-5.

Exhibit 3-5
Parameters Needed to Estimate Control Efficiency for Unpaved Road Watering

	Class A Pan Evaporation (inches)†	Potential Average Hourly Daytime Evaporation Rate (mm/hr)		Hourly Vehicular Traffic Rate (hr^{-1})‡
		Annual	Summer	
Facility A	70	0.34	0.46	4.08
Facility B	65	0.32	0.42	0.05

Generally, the target control efficiency for dust suppression from unpaved roads is used to determine the amount and frequency of water application required. Control efficiencies can fall from approximately 95 percent for total suspended particulates (TSP) (with higher efficiencies for finer particles) shortly after application to approximately 50 percent within five hours of application for unpaved roads with heavy traffic.

As an example, Exhibit 3-6 presents estimated average control efficiencies for annual and summer conditions for Facility A. At an application rate of 1 L/m^2, the average control efficiency for watering every 24 hours is 73 percent for annual conditions and 64 percent for summer conditions.

For Facility B, the extremely low hourly vehicular traffic rate (i.e., only one round-trip every five days) would result in control efficiencies of 99 percent or higher even at low application rates, assuming that the road would be watered at some point during the day prior to each trip. For this analysis, EPA assumed a control efficiency of 70 percent for Facility A, and 99 percent for Facility B, because the Agency believes that these control efficiencies are readily achievable. For example, the assumed control efficiency for Facilty A fall between the mean annual and the summer conditions control efficiencies for daily watering at reasonable application rates. The Agency also believes that higher efficiencies would also be achievable with increases in the frequency or amount of water application.

3.3.4 Soil (Loam) Cover for Storage Piles

EPA found no specific information regarding potential reductions in emissions from covering storage piles with less-erodible material such as soil. Instead, the Agency estimated a control efficiency for this control measure by comparing the relative erodibility of loam (56 tons/acre/year) with sand (220 tons/acre/year) as reported in *Control of Open Fugitive Dust Sources* (Cowherd *et al*., 1988). EPA chose sand as the most appropriate surrogate for uncrusted CKD because sand was the most erodible material for which a value was provided in the reference, and because dry, uncrusted CKD is expected to be highly erodible. The ratio of loam erodibility to sand erodibility yielded an estimated control efficiency of 75 percent.

Exhibit 3-6
Example Control Efficiency Matrices for Watering of Unpaved Roads for Facility A (%)

Annual Conditions									
Application Intensity		Time Between Applications (Hours)							
gal/ft^2	L/m^2	2	4	6	8	12	16	20	24
0.0025	0.10	77.6	55.3	32.9	10.5	-	-	-	-
0.005	0.20	88.8	77.6	66.5	55.3	32.9	10.5	-	-
0.007	0.30	92.5	85.1	77.6	70.2	55.3	40.4	25.5	10.5
0.010	0.40	94.4	88.8	83.2	77.6	66.5	55.3	44.1	32.9
0.012	0.50	95.5	91.1	86.6	82.1	73.2	64.2	55.3	46.3
0.025	1.00	97.8	95.5	93.3	91.1	86.6	82.1	77.6	73.2
0.05	2.00	98.9	97.8	96.6	95.5	93.3	91.1	88.8	86.6
0.07	3.00	99.3	98.5	97.8	97.0	95.5	94.0	92.5	91.1
0.10	4.00	99.4	98.9	98.3	97.8	96.6	95.5	94.4	93.3
0.12	5.00	99.6	99.1	98.7	98.2	97.3	96.4	95.5	94.6
0.15	6.00	99.6	99.3	98.9	98.5	97.8	97.0	96.3	95.5

Summer Conditions									
Application Intensity		Time Between Applications (Hours)							
gal/ft^2	L/m^2	2	4	6	8	12	16	20	24
0.0025	0.10	70.3	40.7	11.0	-	-	-	-	-
0.005	0.20	85.2	70.3	55.5	40.7	11.0	-	-	-
0.007	0.30	90.1	80.2	70.3	60.4	40.7	20.9	1.1	-
0.010	0.40	92.6	85.2	77.8	70.3	55.5	40.7	25.8	11.0
0.012	0.50	94.1	88.1	82.2	76.3	64.4	52.5	40.7	28.8
0.025	1.00	97.0	94.1	91.1	88.1	82.2	76.3	70.3	64.4
0.05	2.00	98.5	97.0	95.6	94.1	91.1	88.1	85.2	82.2
0.07	3.00	99.0	98.0	97.0	96.0	94.1	92.1	90.1	88.1
0.10	4.00	99.3	98.5	97.8	97.0	95.6	94.1	92.6	91.1
0.12	5.00	99.4	98.8	98.2	97.6	96.4	95.3	94.1	92.9
0.15	6.00	99.5	99.0	98.5	98.0	97.0	96.0	95.1	94.1

3.3.5 Latex Binder Addition for Storage Piles

The *Air Pollution Engineering Manual* (Buonicore and Davis, 1992) cites wind tunnel studies of a 2.8 percent solution of Dow Chemical M-167 Latex Binder in water applied at an average intensity of 1.5 gal/yd^2 on low-volatility coking coal. These studies show control efficiencies ranging from approximately 90 percent for TSP at two days after application, dropping to approximately 40 percent at four days after application. For Facility A, EPA assumed the temporary storage piles located at the disposal site to be bulldozed into the landfill at the end of each day, so the high end of control efficiency is assumed. For Facility B, the Agency assumed the temporary storage pile at the plant to accumulate over a five-day period, with each addition to the pile resulting in a disturbance of the entire surface. Accordingly, the Agency assumed latex addition to Facility B's temporary storage to occur after each disturbance of the pile.

3.3.6 Enclose Temporary Storage Pile

As stated in the *Air Pollution Engineering Manual* (Buonicore and Davis, 1992), enclosure of material transfer points and storage piles can result in particulate emission reductions ranging from 70 to essentially 100 percent control, depending on the type of enclosure (partial or full), the type of operation, and whether or not the enclosure vent is routed to a control device such as a baghouse. For this analysis, EPA estimated emissions for both 70 percent control efficiency (partial enclosure) and 99 percent control efficiency (full enclosure).

3.3.7 Cover Truck/Clean Truck and Cover

EPA found no data regarding the effectiveness of these control measures. The Agency estimated the control efficiencies for covering the truck and cleaning the truck and cover after each use at 90 percent and 95 percent, respectively based on engineering judgment and discussions with vendors. (Note that these controls only apply to emissions resulting from wind entrainment of the material in the truck.) Higher efficiencies may be achievable in actual practice.

3.3.8 Rolling of Conditioned CKD

To estimate the emissions due to rolling vehicles over the wet CKD to compact the material, the unpaved road emission equation was used. The silt content was modified to reflect the moisture content of the CKD. The silt content is an estimate of percentage of material with particle diameters less than 75 microns. As more moisture is applied to the CKD, more particles will become agglomerated and the silt content would decrease.

EPA used a two step approach to modeling the emissions resulting from different moisture content assumptions for CKD. The unpaved road model typically uses moisture content to calculate a control efficiency that can be applied to a baseline condition to calculate emissions reductions. In order to get comparability between the two model plants and the different moisture contents, EPA first calculated the percent improvements resulting from three different moisture levels. Using these control efficiencies, an emission factor was calculated using the unpaved roads equation and solving for the silt content that produced the calculated emissions reduction associated with the previously calculated control efficiency. It is likely that this underestimates the emissions reductions that would actually result in wet compaction because the fine particles in CKD would also bind chemically.

One percent moisture content was used as a baseline condition and 10%, 30%, and 50% moisture content was modeled. Using the equation 3.3.8-1 for water addition to storage piles/landfill (see Section 3.3.2) and the unpaved roads equation 3.3.8-3 (see Section 3.3.3), EPA developed a relationship between moisture content and silt content. Uncontrolled emission factors were developed (assuming 90% silt content) using the unpaved roads equations. Control efficiencies were developed for each of the predetermined moisture contents using the water addition equation.

$$CE = 100 * (1- M_u^2/M_c^2) \qquad \text{eqn. 3.3.8-1}$$

Where:

CE = Control Efficiency
M_u = Moisture Content of Dry CKD = 1%
M_c = Moisture Content of Wet CKD = 10%, 30%, and 50%

The unpaved roads equation was used to establish the baseline uncontrolled emissions for a moisture content of 1 percent and a silt content of 90%. Control efficiencies were calculated using the water addition equation and the moisture contents of 10%, 30%, and 50% for M_c while the uncontrolled moisture content, M_u remained 1%. The control efficiencies were then applied to the uncontrolled emissions factor to create the emissions factors for each of the three moisture contents using equation 3.3.8-2. These three emission factors (in lb per vehicle mile traveled) were then used to solve for the silt content from the unpaved road model equation (equation 3.3.8-3). The unpaved road model was rerun to find a silt content that was consistent with the control efficiencies estimated for the different moisture levels.

$$E_c(\text{lb/VMT}) = E_u \text{ x } (1 - CE)/100 \qquad \text{eqn. 3.3.8-2}$$

$$E\ (\text{lb/VMT}) = k \text{ x } (5.9) \text{ x } (s/12) \text{ x } (S/30) \text{ x } (W/2.7)^{0.7} \text{ x } (w/4)^{0.5} \text{ x } [(365-p)/365] \qquad \text{eqn. 3.3.8-3}$$

Where:

E = Emission Factor of Unpaved Road Emissions
k = Particle Size Multiplier
s = Silt Content = 90% for Dry CKD
S = Mean Vehicle Speed = 4 mph
W = Mean Vehicle Weight = 75 tons
w = Mean Number of Wheels = 4
p = Days With Greater Than 0.01" Precipitation
    p = 115 days for Facility B
    p = 79 days for Facility A

Uncontrolled emissions of CKD due to rolling activities were calculated for both Facility A and Facility B and are presented in Exhibit 3-7 below. Control efficiencies were then determined for each moisture content and then controlled emissions were estimated. These emissions were then used to back calculate a silt content from the unpaved road equation. The results are listed below. The emissions from wet compaction of CKD when moisture content is above 10% are quite small.

These low emission values for wet CKD have been verified through EPA's plant visits and through the observation of videos of facilites using water addition to CKD as well as activities at those facilities under uncontrolled conditions.

Exhibit 3-7
Moisture Contents and Corresponding Silt Contents

Mc Moisture Content (%)	CE Control Efficiency (%)	Facility A		Facility B	
		Ec * (lb/VMT)	s (silt) (%)	Ec * (lb/VMT)	s (silt) (%)
1(baseline)	0.00	37.9	90	33.13	90
10	99.00	0.379	0.9	0.331	0.9
30	99.89	0.0421	0.1	0.0368	0.1
50	99.96	0.0152	0.036	0.0133	0.036

*Ec = emission factor for compaction in pounds (lb) per vehicle mile traveled (VMT).

The silt content values were then used to determine emission factors for the rolling emissions developed by the unpaved roads equation. The silt contents for wet CKD are also quite small. As previously mentioned, it is possible that actual silt contents will be lower due to chemical reaction in the CKD. However, emissions are so low that this impact is probably not significant.

Total emissions from the rolling of the wet CKD were calculated using the emission factors calculated and shown in Exhibit 3-7 and applying the vehicle miles traveled (VMT) per year to compact the wet CKD. Total amounts of CKD deposited in the monofill by each sample facility were used to determine the amount of VMT. Wet CKD was assumed to be deposited into the monofill in 3 yard wide and 1 yard deep lifts and rolled over twice by a 4 wheeled tractor. The amount of wet CKD deposited in the monofill was calculated by the size of the truck and the number of trips made per year for each example facility.

3.3.9 Wet Compaction

The wet compaction scenario is based on CKD management activities observed by EPA at the Lafarge facility in Alpena, Michigan. Alpena has proposed wet transfer and dumping followed by spreading the wet CKD and compacting it by driving over the material. For most of this scenario, the emissions would be the similar to other scenarios already presented. The higher moisture content of wet compaction has some impact on overall emissions. Moisture contents of 10%, 30% and 50% were modeled to bracket the expected ranges of moisture content for wet compaction. The unique step in this process is the compaction into horizontal lifts by rolling with heavy equipment. This estimate uses a modified unpaved road scenario based on driving heavy equipment over a surface of 100% CKD at low speeds.

To determine the overall impacts of these different approaches, EPA developed emissions estimates for four distinct sequences:

> Loading of wet CKD slurry onto trucks causing fugitive dust due to handling activities (see Section 3.1.2.2 for an explanation of equations);
>
> Transportation of the CKD to the disposal site causing fugitive dust through wind entrainment from the truck, and unpaved roads (see Section 3.1.2.3 for an explanation of equations);
>
> Unloading of CKD from the trucks causing fugitive dust resulting from dumping (see Section 3.1.2.2 for an explanation of equations); and
>
> Wet compaction of the wet CKD in the disposal area causing dust emissions due to the mechanical disturbance of the CKD (see Section 3.3.8 for an explanation of equations).

The results of these emissions modeling are summarized in Exhibit 3-8. It can be seen from these results that emissions from CKD with a high moisture content (above 10%) are very low in all stages of management. The majority of the emissions under the wet compaction scenarios result from the wetted haul roads. The roads are modeled using the wetting assumptions described in Section 3.3.3. The fact that the trucks that are driving on the roads contain wet CKD is not assumed to have any impact on the roadway emissions.

Exhibit 3-8
Emissions from Wet Compaction Scenario (lbs/yr)

Moisture Content	Facility B			Facility A		
	PM-30	PM-10	PM-2.5	PM-30	PM-10	PM-2.5
Enclosed Temporary Storage	0.00	0.00	0.00	0.00	0.00	0.00
Loading of Conditioned CKD						
10%	1	0	0	39	19	6
30%	0	0	0	8	4	1
50%	0	0	0	4	2	1
Covered Truck Entrainment	7	4	1	677	338	135
Wetted Unpaved Roads	192	86	23	40,210	18,095	4,775
Unloading of Conditioned CKD						
10%	1	0	0	39	19	6
30%	0	0	0	8	4	1
50%	0	0	0	4	2	1
Wet Compaction Conditioned CKD*						
10%	0	0	0	10	5	1
30%	0	0	0	1	1	0
50%	0	0	0	0	0	0
Covered CKD Lifts	0	0	0	0	0	0
Total						
10%	200	90	25	40,976	18,475	4,923
30%	199	90	24	40,905	18,441	4,913
50%	199	90	24	40,895	18,437	4,912

**Note: Wet compaction assumes mechanical compression through rolling.*

Chapter 4: Proposed Standards

This chapter provides a summary of EPA's proposed standards for controlling fugitive dust emissions from cement kiln dust landfill (CKDLF) units. A CKDLF unit is defined as a discrete area of land or an excavation that receives CKD waste, and that is not a land application unit, surface impoundment, injection well, or waste pile. A CKDLF unit may receive other types of non-hazardous industrial wastes, such as kiln brick, construction debris, mining overburden or other commercial industrial waste. A CKDLF unit may be a new CKDLF unit, an existing CKDLF unit or a lateral expansion of an existing unit.

EPA has proposed air protection standards for all new and existing CKD waste landfill units, except units closed prior to the effective date of the rule and units that receive waste-derived CKD that exhibits a characteristic of hazardous waste.[3] Any expansion of an existing CKD landfill unit, defined as any horizontal or vertical expansion of the waste boundary of an existing landfill unit, are considered new units and must meet the requirements applicable to new units. Under this proposed definition, any area of any existing unit that receives waste after the effective date of this rule is an expansion. EPA has also proposed that interim storage units, such as containers or buildings which contain CKD destined for recycling or sale, must also comply with the air performance standard.

These standards could be met in one of two ways. First, a facility could obtain a determination from an authorized State or (in unauthorized States) from the EPA Regional Administrator that a management practice or alternative design meets the standard, providing adequate assurance that the unit is managed to control wind dispersal of particulate matter. Second, the facility could design units according to technology-based standards outlined below, so as to obviate the need for such a demonstration.

The standards to control fugitive dust emissions from CKDLF units include a performance standard (Section 4.1) and default technical standards that meet the performance standard (Section 4.2).

4.1 Performance Standard

Under EPA's proposal, unit design and operation must ensure that wind dispersal of particulate material (PM) is controlled. The specific performance standard for air is that the owner or operator of a facility must cover or otherwise manage the unit to control wind dispersal of CKD waste. This standard would apply to solid PM that becomes airborne directly or indirectly as a result of CKD handling procedures. The most common sources of PM at cement manufacturing

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[3] The proposed standards to not apply to CKD from kilns that burn hazardous waste as a fuel when the CKD is a hazardous waste as defined by 40 CFR part 261. Such waste-derived characteristically hazardous CKD continues to be subject to the provisions of 40 CFR 266.112.

facilities to which this standard applies includes vehicular traffic on unpaved roads or on CKD waste management units, and wind erosion from waste management units. This standard would not apply to CKD emitted from an exhaust stack.

The Agency understands that methods for controlling fugitive dust will vary depending on factors such as geographic location, climate, facility design, and CKD management method. Therefore, the proposal provides owners and operators, working with State agencies, with substantial flexibility do determine the appropriate method to control fugitive emissions based on facility-specific conditions.

To demonstrate compliance with the performance standard for the protection of air, EPA has proposed that owners or operators of new and existing CKD landfills employ the technology-based standards described below for controlling fugitive dust. For example, an owner or operator may employ all of the following to demonstrate compliance with the performance standard for the protection of air:

- emplace CKD waste in a landfill as conditioned CKD;
- cover the waste in the landfill at the end of each operating day with material sufficient to prevent blowing dust;
- water unpaved roads with sufficient frequency to prevent blowing dust;
- use covers on trucks transporting CKD; and
- place CKD destined for temporary storage prior to recycling, sale, or disposal in tanks, containers, or buildings.

4.2 Technical Standards That Meet the Performance Standard

4.2.1 Conditioning

For facilities complying with the technology-based standards, EPA has proposed that CKD managed in landfills must be emplaced as conditioned CKD. Proper conditioning includes mixing the CKD with water on a continuous or batch basis, such as pug-milling, followed by compaction. The material should be spread in lifts of uniform thickness and compacted to the required density with appropriate equipment (e.g., a heavy sheeps-foot roller). The Agency believes that compaction of moist CKD, coupled with the waste’s natural cementitious properties enables individual waste particles to bond together, thus greatly reducing the availability of particulate material for air dispersal, and thus, this standard is protective for fugitive dust from landfills. For purposes of this section, *conditioned CKD* means cement kiln dust that has been compacted in the field at appropriate moisture content using moderate to heavy equipment to attain 95% of the standard Proctor maximum dry density value according to ASTM D 698 or D 1557 test methods.

4.2.2 Covers

The Agency has also proposed that disposed CKD be covered with material at the end of each operating day sufficient to prevent blowing dust. EPA believes that cover material applied at the end of each operating day over the active face of the CKD landfill will prevent the entrainment of CKD as fugitive dust, and is a more effective practice for dust suppression than frequent wetting and watering[4]. The cover must be constructed of materials that have appropriate physical and chemical properties, and sufficient strength and thickness to prevent failure due to physical contact with CKD, climactic conditions, the stress of installation, and the stress of daily operation. Similarly, EPA has proposed that CKD transported in trucks on or off the facility be covered to minimize fugitive emissions of CKD. Alternative materials or actions may be approved by the State (or, in unapproved States by the EPA Regional Administrator), as long as the facility makes a demonstration that the alternative meets the performance standard.

4.2.3 Wetting

EPA believes that consistent wetting and watering of unpaved roads can sufficiently reduce releases of fugitive emissions from facilities that manage CKD. As discussed above in Section 3, fugitive dust emissions from unpaved roads can be significantly reduced by increasing the moisture content of the dust.

4.2.4 Temporary Storage

The Agency has proposed that CKD destined for temporary storage prior to recycling, sale, or disposal not be placed in land-based units, but in tanks, containers, or buildings. CKD would not be a hazardous waste provided the storage that precedes sale or recycling does not entail land placement. An acceptable building containment unit must be a man-made structure with a foundation constructed of non-earthen materials, have walls (which may be removable), and have a roof suitable for diverting rainwater away from the foundation. In considering these criteria for containers and buildings, EPA is placing special emphasis upon practical considerations, such as the need to transport materials in and out of the unit in a reasonable fashion. The Agency would not require that these units meet full Subtitle C requirement for storage of hazardous wastes as outlined in Part 265 Subpart J.

4.3 Application of the Technology-Based Standard to Model Plants

The technology-based standard proposes four majors areas of control, these are:

Conditioning,

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[4] Although wetting and watering is a common fugitive dust suppression practice at CKD landfills, the persistent releases of fugitive CKD reported in the *Report to Congress on Cement Kiln Dust* suggest that frequent wetting alone is not sufficient to prevent blowing dust.

Covers,
Wetting, and
Enclosure of Temporary Storage.

As this document demonstrates, there are a wide variety of control techniques and technologies that can be successfully applied to control of CKD. The performance of most of these will vary from site to site. The technology-based standard proposes a set of control technologies that have the potential to provide a high level of emissions control under a variety of circumstances. The proposed Rule allows for flexible implementation for facilities wishing to employ and demonstrate alternative control techniques.

EPA has applied the technical standard to the two model plant scenarios and compared these technical standards to baseline, uncontrolled emissions in order to calculate the overall emissions reduction that can be achieved by complying with the standards. Exhibit 4-1 presents the percent emissions reductions achieved by implementing the technology-based standards in comparison to an uncontrolled emissions baseline.

Exhibit 4-1
Control Efficiencies Achieved by Technology-Based Standard

Moisture Content	**Facility B**			**Facility A**		
	PM-30	**PM-10**	**PM-2.5**	**PM-30**	**PM-10**	**PM-2.5**
Uncontrolled Emissions Estimates (lbs/yr) (from Exhibit 3-3)						
na	27,494	13,662	5,359	85,672,071	43,459,254	9,024,365
Emissions Estimates (lbs/yr) for a Wet Compaction Scenario Meeting the Requirements of the Proposed Technology-Based Standard (from Exhibit 3-8)						
10%	200	90	25	40,976	18,475	4,923
30%	199	90	24	40,905	18,441	4,913
50%	199	90	24	40,895	18,437	4,912
Percent Reduction Achieved Over Uncontrolled Scenario Through Application of Technology-Based Standard						
10%	99.27%	99.34%	99.53%	99.95%	99.96%	99.95%
30%	99.28%	99.34%	99.55%	99.95%	99.96%	99.95%
50%	99.28%	99.34%	99.55%	99.95%	99.96%	99.95%

The emissions reductions in Exhibit 4-1 represent control improvements over uncontrolled emissions. Because most facilities currently operate with some fugitive dust controls, these estimates do not necessarily represent typical current industry practice. In addition, due to the use of simplifying and conservative assumptions (such as the “fastest mile” values used to calculate wind erosion), the estimates of uncontrolled conditions represent upper bound or high end estimates. Actual percent reductions achievable at a typical facility implementing the technology-based standard might be lower than those estimated for the sample plants. However the Agency believes this analysis demonstrates the proposed technology-based standard represents a high level of emissions reduction that can be achieved using currently available and implementable technologies.

Chapter 5: Implementation

5.1 Implementation of Fugitive Dust Control Technologies

As described in Chapter 4, the Agency is proposing standards to control fugitive dust emissions of CKD at cement manufacturing facilities. Under the proposed regulations, owners or operators will be required to control fugitive dust emissions (1) from tanks, containers, or buildings used for temporary storage of CKD for recycling, sale or final disposal, (2) from trucks transporting CKD, and (3) at CKD landfills. This section describes technical considerations for implementation of the proposed standards for control of fugitive emissions from CKD management activities.

5.1.1 Control of Fugitive Dust Emissions from Tanks, Containers, or Buildings

Under the proposed rule for CKD, the Agency is proposing standards to control fugitive emissions from cement kiln dust waste placed in temporary storage. Temporary storage of CKD includes CKD tanks, containers or buildings. To control fugitive emissions, the temporary storage unit must meet the following minimum standards:[5]

> The tank, container, or building should be an engineered structure with a man-made floor, walls, and a roof all of which prevent water from reaching the stored CKD and are made of non-earthen materials providing structural support.
>
> The tank, container, or building must be free standing and not a surface impoundment (as defined in 40 CFR 260.10), be manufactured of a material suitable for storage of its contents, and meet appropriate specifications such as those established by either ASTM, API, or UL standards.

In implementing these standards, owner/operators may make a demonstration to the State that alternative measures will control wind dispersal of dust without presenting a threat to human health and the environment. The owner or operator must place the demonstration in the operating record and notify the State that it has been placed in the operating record.

5.1.2 Control of Fugitive Dust Emissions from Transport of CKD Via Trucks

Under the proposed rule for CKD, the Agency is proposing standards to control fugitive emissions during the transport of CKD in trucks to a CKDLF units. In implementing the regulations, owner/operators must cover vehicles or otherwise manage the CKD to control wind dispersal of dust. Sources of emissions can include CKD in the truck beds, CKD on the trucks, and CKD on roadways. While the proposed technical standard applies to cover on truck,

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[5] For purposes of this section, *temporary storage* means interim storage of CKD designated for recycling, sale or final disposal.

owner/operators may wish to also use other good housekeeping methods such as moisture addition to roads and periodic cleaning of trucks.

Alternative measures for dust control may be approved by the State if a demonstration is made that the alternative controls wind dispersal of dust without presenting a threat to human health and the environment. The owner or operator must place the demonstration in the operating record and notify the State Director that it has been placed in the operating record.

5.1.3 Control of Fugitive Dust Emissions at CKDLF Units

The Agency is proposing standards to control fugitive emissions at CKDLF units. Under the proposed standards, CKD disposed in all CKDLF units must be managed in a manner that does not violate any applicable requirements developed under a State Implementation Plan (SIP) approved or promulgated by the Administrator pursuant to section 110 of the Clean Air Act, as amended.

In implementing these standards, the owner or operator must dispose CKD in CKDLF units and expansions constructed so that such CKD is:

1. Covered or otherwise managed to control wind dispersal of dust, or
2. Emplaced as conditioned[6] CKD to control wind dispersal, and
3. Covered with a sufficient thickness of earthen material at the end of each operating day, or at more frequent intervals if necessary to control blowing dust.

If approved by the State, an owner or operator may use alternative materials and actions for fugitive CKD control. To use an alternative material or action, owner/operators must demonstrate to the State that the alternative controls blowing dust without presenting a threat to human health and the environment. The owner or operator must place the demonstration in the operating record and notify the State that it has been placed in the operating record.

The Agency has identified two CKD-based products have been identified for potential use as a daily or intermediate cover for a CKD landfill. The Report to Congress (USEPA, 1993b) identifies a product known as N-Viro Soil®, which is a mixture of CKD and sewage sludge, and notes its use as a cover at landfills. A product known as Posi-Shell®, also CKD-based, has also been used as a cover material at landfills. As part of the evaluation of CKD as landfill liners and

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[6] For purposes of this section *conditioned CKD* means cement kiln dust that has been compacted in the field at appropriate moisture content using moderate to heavy equipment to attain 95% of the standard Proctor maximum dry density value according to ASTM D 698 or D 1557 test methods.

caps[7], N-Viro Soil®, and Posi-Shell®, were briefly evaluated based on vendor information and available information.

5.2 Reporting and Recordkeeping

In implementing the fugitive dust control provisions of the proposed rule, owner/operators have the option of demonstrating to the State the effectiveness of alternatives to control fugitive dust emissions during temporary storage, transport, and landfilling of waste CKD. Such a demonstration must be placed in the operating record of the facility and the owner/operator must notify the State that such a demonstration has been made. Alternatives to earthen cover materials must be approved by the State.

In addition, any deviations from the default technical standards (or demonstrated alternative measures) must be documented in the facility's operating record.

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[7] For additional information, see Sections 6.4.5.1 and 6.4.5.2 of the *Technical Background Document on Ground Water Controls at CKD Landfills* in today's docket.

References

Buonicore A. and W. Davis, *eds.*, 1992. *Air Pollution Engineering Manual.* Air & Waste Management Association. New York: Van Nostrand Reinhold.

Cowherd, Jr., C., *et al.*, 1985. *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*, EPA 600/8-85/002, U.S. Environmental Protection Agency, Office of Research and Development, February, 1985.

Cowherd, Jr., C., *et al.*, 1988. *Control Of Open Fugitive Dust Sources*, EPA 450/3-88-008, U. S. Environmental Protection Agency, Research Triangle Park, NC, September 1988.

Kohlhaas, B., et al., 1983. *Cement Engineer's Handbook.* Bauverlag GMBH, Wiesbaden and Berlin.

Portland Cement Association, 1991. *PCA Cement Kiln Dust Survey.* Washington, D.C. December, 1991.

Portland Cement Association, 1995. *U.S. and Canadian Portland Cement Industry: Plant Information Summary (December 31, 1995).*

Portland Cement Association, 1997. Survey of Industry [NEED FORMAL TITLE].

Sell, N. and F. Fischbach, 1978. "Pelletizing Waste Cement Kiln Dust for More Efficient Recycling." *Ind. Eng. Chem. Process Des. Dev.*, 17(4).

Todres, H., *et al.*, 1992. "Cement Kiln Dust Management Permeability," PCA Research and Development Bulletin RD103T, Portland Cement Association.

U.S. Environmental Protection Agency, 1993. *Report to Congress on Cement Kiln Dust.* Office of Solid Waste, Washington, D.C., December 1993.

U.S. Environmental Protection Agency, 1994. *Report to Congress Public Comment Summary and Response Document on Cement Kiln Dust.* Office of Solid Waste, Washington, D.C., August, 1994.

U.S. Environmental Protection Agency, 1994. *Technical Background Document for the Notice of Data Availability on Cement Kiln Dust, Human Health and Environmental Risk Assessment, in Support of the Regulatory Determination on Cement Kiln Dust.* Office of Solid Waste, Washington, D.C., August, 1994.

U.S. Environmental Protection Agency, 1995. *Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources,* AP-42 Fifth Edition, U.S. Environmental Protection Agency, Research Triangle Park, NC, January 1995.

U.S. Environmental Protection Agency, 1995. *Regulatory Determination on Cement Kiln Dust, Final Rule*. Federal Register, Vol. 60, No. 25, Tuesday, February 7, 1995.

U.S. Environmental Protection Agency, 1997. *Technical Background Document: Population Risks from Indirect Exposure Pathways, and Population Effects from Exposure to Airborne Particles from Cement Kiln Dust Waste*. Office of Solid Waste, Washington, D.C., June, 1997.

U.S. Environmental Protection Agency, 1998a. Personal communication with Frank Smith, Office of Solid Waste.

U.S. Environmental Protection Agency, 1998b. Video tapes, Lafarge Corp.'s Alpena facility in Michigan. Tape #1: Alpena dust handling, March 1994; Tape #6: Air, Water, Dust, 6/92 to 10/93; Tape #11: Fugitive Dust Stack and Water Emissions; Tape #12: Dust and Stack Emissions.