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PARTICULATE EMISSION FACTORS FOR THE CONSTRUCTION AGGREGATE INDUSTRY

Draft Final Report

by

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SECTION 1.0
INTRODUCTION

Over the past several years, the Environmental Protection Agency (EPA) has been working with construction aggregate industry representatives to update the particulate emission factors presented in AP-42. Currently there are two sections covering this industry: stone quarry processing and sand and gravel processing. These sections are dated December 1975 and April 1973, respectively. The current effort is to combine these sections into one covering the construction aggregate industry.

This report includes particulate emission tests conducted by EPA's Emission Standards and Engineering Division (ESED), Office of Air Quality Planning and Standards (OAQPS) during the development of standards of performance for the nonmetallic mineral industry, particulate emission estimates for segments of the industry prepared for EPA's Industrial Environmental Research Laboratory, and particulate emission estimates based on testing performed for the industry's trade associations. The objective of this report is to present the results of this data gathering and analysis effort. The report is divided into three major areas. First, background information related to the processes in the construction aggregate industry is presented, with a process flow chart. Second, all of the particulate source test data is presented. Third, the methodology for selecting single source specific emission factors and the resulting particulate emission factors are presented.

As with all average or "typical" emission factors, they are obtained from a wide range of data of varying degrees of accuracy. The reader must be cautioned not to use these emission factors indiscriminately, because the factors may not yield precise emission estimates for an individual installation. Only on-site source tests can provide data sufficiently accurate and precise to determine actual emissions for a specific source. Emission factors are most appropriate when used in diffusion models for the estimation of the impact of proposed new sources upon the ambient air quality and for community or nationwide air pollution emission estimates.

SECTION 2.0

BACKGROUND

2.1 GENERAL[1]

The processing of construction aggregate (crushed stone or sand and gravel) usually involves a series of distinct yet interdependent operations. These include quarrying or mining operations (drilling, blasting, loading and hauling) and plant process operations (crushing, grinding, conveying and other material handling and transfer operations). Many kinds of construction aggregate require additional processing (washing, drying, etc.) depending on rock type and consumer requirements. Some of the individual operations can be associated with a high degree of moisture, such as wet crushing and grinding, washing, screening and dredging. These wet processes do not generate appreciable particulate emissions and will not be discussed here. Dry processing operations are potentially significant sources of nuisance particulate emissions which can cause local violations of ambient particulate standards. The generally large particles comprising these emissions can usually be controlled quite readily and satisfactorily to prevent such problems.

The construction aggregate industry can be broken into various categories, depending on source, mineral type or form, physical characteristics, wet versus dry, washed or unwashed, and end uses. For the purposes of this Section, the industry is discussed in two categories: sand and gravel and crushed stone. Sand and gravel are mined wet and consist of discrete particles or stones, while crushed stone normally originates from solid strata which are broken by blasting and require substantial crushing to be useful as a consumer product.

Particulate emission sources in the construction aggregate industry can be classified as (a) process fugitive emission sources and (b) open dust sources. Process fugitive emissions and open dust sources are both defined as any emissions not entering the atmosphere from a duct, stack or flue. Open dust sources traditionally have included: (a) vehicular traffic on paved and unpaved roads, (b) initial dumping or loading of raw material into the crushing operations, and (c) wind erosion from storage piles and exposed terrain, while all other nonducted sources have been classified as process fugitive emissions. This report addresses only process fugitive emission sources.

Most aggregate require additional processing depending on the rock type and consumer requirements. In certain cases, stone washing may be required to meet particular end product specifications or demands such as for concrete aggregate. Some minerals, especially certain lightweight aggregates, are washed and dried, sintered, or treated prior to primary crushing. Others are dried following secondary crushing. Sand and gravel, crushed and broken stone, and most lightweight aggregates normally are not milled and are screened and shipped to the consumer after secondary or tertiary crushing. Some sand and gravel operations are wet process operations and may require little, if any, crushing operations.

Figure 2-1 contains a process flow diagram for a representative construction aggregate plant. For the purposes of developing emission factors, the plant has been divided into the following operations: primary crushing and screening; secondary crushing and screening; tertiary crushing and screening; and dry grinding and screening.

2.2 PRIMARY CRUSHING OPERATIONS

Construction aggregate material is normally delivered to the processing plant by truck, and dumped into a hoppered feeder, usually a vibrating grizzly type, or onto screens. These screens separate or scalp the larger boulders from the finer rocks that do not require primary crushing, thus minimizing the load to the primary crusher. Jaw or gyratory crushers are usually used for initial reduction. The crusher product, normally 7.5 to 30 centimeters (3 to 12 inches) in size, and the grizzly through (undersize material) are discharged on to a belt conveyor and normally transported to either secondary screens and crusher, or to a surge pile or silo for temporary storage.

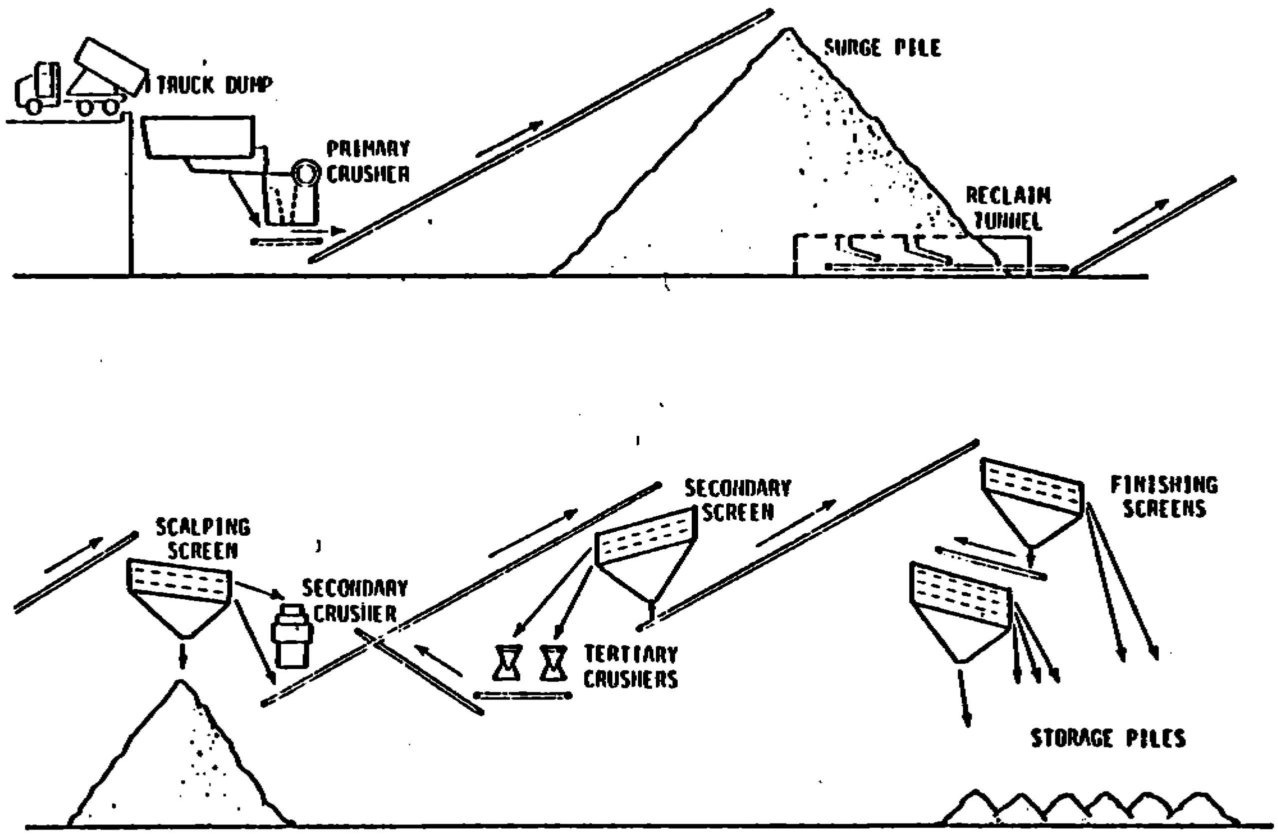

Figure 2-1. Flowsheet of a typical crushing plant.

The secondary screens generally separate the process flow into either two or three fractions (oversize, undersize, and through) prior to the secondary crusher. The oversize is discharged to the secondary crusher for further reduction. The undersize, which requires no further reduction at this stage, normally bypasses the secondary crusher. A third fraction, the throughs, is separated when processing some minerals. Throughs contain unwanted fines that usually are removed from the process flow and stockpiled as crusher-run material.

2.3 SECONDARY CRUSHING OPERATIONS

For secondary crushing, gyratory or cone crushers are most commonly used, although impact crushers are used at some installations. The product from the secondary crushing stage, usually 2.5 centimeters (1 inch) or less in size, is normally transported to a secondary screen for further sizing. Sized material from this screen is either discharge directly to a tertiary crushing stage or conveyed to a fine ore bin which supplies the milling or dry grinding stage.

2.4 TERTIARY CRUSHING AND DRY GRINDING OPERATIONS

Cone crushers or hammermills are normally used for tertiary crushing. Rod mills, ball mills and hammermills are normally used in the milling or dry grinding stage. The product from the tertiary crusher or the mill is usually conveyed to a type of classifier such as a dry vibrating screen system, an air separator, or a wet rake or spiral system (if wet grinding is employed) which also dewaters the material. The oversize is returned to the tertiary crusher or mill for further size reduction. At this point, some mineral end products of the desired grade are conveyed directly to finished product bins, or are stockpiled in open areas by conveyors or trucks.

SECTION 3.0
EMISSION FACTORS AND SUPPORT DATA

This section presents particulate emission factors (EFs) applicable to construction aggregate industry sources and also the details of the process operation and test methodology necessary to evaluate the reliability of the EFs. A reliability rating is given to each EF based on the following scale:

Rating	Rating Descriptions
A	Tests performed by a sound methodology and reported in enough detail for adequate validation.
B	Tests performed by a generally sound methodology but lack enough detail for adequate validation.
C	Tests based on an untested or new methodology or lack a significant amount of background data.
D	Tests that are based on a generally unacceptable method.

Table 3-1 lists the test reports used in this section. The table shows the material processed, the testing devices used, and the processes tested at each plant.

3.1 UNCONTROLLED EMISSIONS

3.1.1 Primary Crushing Operations

The uncontrolled emissions test data for primary crushing operations are shown in Table 3-2. Average EFs and the test ratings along with process parameters are presented. There are six A-rated EFs, four B-rated EFs, and two C-rated EFs.

TABLE 3-1. CONSTRUCTION AGGREGATE EMISSION TESTS

Company name/ data source	Publication number	Type of rock	Measurement device	Production process tested
Exxon Minerals Company Casper, WY	79-MET-1	Tertiary Fluvial Sandstones	Method 5 Train Andersen Cascade Impactor	Primary Crushing
Climax Molybdenum Company Silverthorne, CO	79-MET-2	Fine and Coarse-Grained Quartz-Fluorite-Molybdenite; Quartz-Sercite-Pyrite; Quartz-Fluorite-Sphalerite-Galena-Rhodochrosite	Method 5 Train	Primary Crushing
Anaconda Copper Company Butte, MT	79-MET-3	Chalcocite Chalcopyrite Enargite Borxite	Method 5 Train Andersen Cascade Impactor	Primary Crushing
Cypress Bagdad Copper Company Bagdad, AZ	79-MET-4	Quartz-Monzonite Rock		Secondary Crushing
New Jersey Zinc Company Ogdensburg, NJ	80-MET-6	Franklinite Willemite Zincite	Method 5 Train Andersen Cascade Impactor	Tertiary Crushing Dry Grinding
Homestake Mining Company Lead, SD	80-MET-7	Cummingtonite Sideroplesite Vein Quartz Minor Sulfides	Method 5 Train	Primary Crushing Secondary Crushing
Union Carbide Company Hot Springs, AR	80-MET-8	Mixture of Igneous Rock Complexes with Sedimentary (Clay) Intrusions	Method 5 Train Andersen Cascade Impactor	Dry Grinding
Source Assessment: Crushed Limestone	EPA-600/2-78-004e	Limestone	High-Volume Sampler Respirable Dust Monitor (D_{50} - 3.5 microns)	Primary Crushing (Plant A) Secondary Crushing (Plant B)

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TABLE 3-1. (continued)

Company name/ data source	Publication number	Type of rock	Measurement device	Production process tested
Source Assessment: Crushed Stone	EPA-600/2-78-004L	Traprock	High-Volume Sampler Respirable Dust Monitor (D_{50} - 3.5 microns)	Primary Crushing (Plant A) Secondary Crushing (Plant A) Fines Crushing (Plant A) Secondary Crushing (Plant B) Tertiary Crushing (Plant B) Fines Crushing (Plant B)
Emissions From the Crushed Granite Industry	EPA-600/2-78-021	Granite	High Volume Sampler Respirable Dust Monitor (D_{50} - 3.5 microns)	Secondary Crushing (Plant A) Secondary Crushing (Plant B)
Particulate Emissions From Stone Crushing Operations	Monsanto/TRC	Granite	Tracer Gas Analysis (Sulfur Hexafluoride) and Respirable Dust Monitor (D_{50} - 3.5 microns)	Primary Crushing Secondary Crushing Tertiary Crushing Fines Crushing
		Sand and Gravel (1)		Primary Crushing Secondary Crushing
		Sand and Gravel (2)		Primary Crushing Secondary Crushing
		Traprock		Primary Crushing Secondary Crushing Tertiary Crushing Fines Crushing
		Limestone (1)		Secondary Crushing
		Limestone (2)		Secondary Crushing
		Limestone (3)		Secondary Crushing Tertiary Crushing

CONTINUED

TABLE 3-1. (continued)

Company name/ data source	Publication number	Type of rock	Measurement device	Production process tested
Arizona Portland Cement Rillitto, AZ	74-STN-1	Limestone	Method 5 Train	Primary Crushing Secondary Crushing
Ferrante and Sons Bernardsville, NJ	75-STN-6	Traprock	Method 5 Train	Tertiary Crushing
J.M. Brenner Company Lancaster, PA	75-STN-7	Limestone	Method 5 Train	Primary Crushing Secondary Crushing
Kentucky Stone Company Russellville, KY	75-STN-8	Limestone	Method 5 Train	Primary Crushing
Engelhard Minerals and Chemical Company Attapulgus, GA	78-NMM-6	Fuller's Earth	In Stack Filter (Method 17)	Dry Grinding

TABLE 3-2. PRIMARY CRUSHING OPERATION UNCONTROLLED EMISSION TESTS

	Average emission rate (lb/ton)	Test rating	Range of test data (lb/ton)	Emissions <2.5 microns (lb/ton)	Emissions <10 microns (lb/ton)	Company name/data source	Location of measurement device	Number of runs	Process Conditions: Average production (tons/hr)	Process Conditions: Average moisture content	Process Conditions: Type of rock	Average flow rate (acfm)	Particle size-D50 (microns)
1.	0.017	A	0.015-0.018			J.M. Brenner (75-STN-7)	Baghouse Inlet	2	123	0.6	Limestone	1,105	--
2.	0.686	A	0.558-0.793			Kentucky Stone (75-STN-8)	Baghouse Inlet	3	353	0.8	Limestone	4,687	--
3.	0.658	A	0.489-0.841	0.004	0.046	Anaconda (79-MET-3)	Baghouse Inlet	3	2,118	1.5	Chalcocite Chalcopyrite Energite Borxite	87,167	>10
4.	0.041	A	0.029-0.056		0.016	Homestake Mining (80-MET-7)	Baghouse Inlet	3	124	4.0	Cummingtonite Sideroplesite Vein Quartz Minor Sulfides	2,314	>10
5.	0.0014	A	0.0008-0.0022	0.0008	0.0012	Exxon Highland (79-MET-1)	Scrubber Inlet	3	391	5.6	Tertiary Fluvial Sandstones	8,893	1.1
6.	0.034	A	0.031-0.036	0.003	0.015	Climax Co. (79-MET-2)	Scrubber Inlet	3	1,080	4.0	Fine- and coarse grained quartz-fluorite-molybdenite; quartz-sericite-pyrite; quartz-fluorite-sphalerite-galena-rhodochrosite	55,688	>10
7.	0.0011	C	--	--	0.0003	Crushed Limestone (EPA 600/2-78-004E)	50 Feet Downwind		209	--	Limestone		3.5
8.	--	C	--	--	0.003	Crushed Stone (EPA 600/2-78-004L)	328 Feet Downwind		600	--	Traprock		3.5

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TABLE 3-2. (continued)

	Average emission rate (lb/ton)	Test rating	Range of test data (lb/ton)	Emissions <2.5 microns (lb/ton)	Emissions <10 microns (lb/ton)	Company name/data source	Location of measurement device	Number of runs	Process Conditions: Average production (tons/hr)	Process Conditions: Average mois-ture content	Process Conditions: Type of rock	Average flow rate (acfm)	Particle size-D_{50} (microns)
9.	0.0015	B	--		0.0008	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	6	--	--	Traprock		3.5
	--	B	--		0.01	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	6	--	--	Granite		3.5
	--	B	--		0.0006	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	9	--	--	Sand & Gravel (1)		3.5
	--	B	--		0.001	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	10	--	--	Sand & Gravel (2)		3.5

For the A-rated EFs, there is an obvious correlation between the moisture content of the rock and the magnitude of the EF. All of the A-rated EFs are based on measurements taken in the inlet stream to a control device.

The B-rated EFs were estimated using a respirable dust monitor and a tracer, sulfur hexafluoride (SF_6), which was released at a known emission rate from the source and collected 30 feet downwind in Tedlar bags. Because there are no data on the moisture content of the material being processed or the processing equipment and conditions, these EFs were rated lower than the instack measurements.

The C-rated EFs were estimated using a respirable dust monitor to measure the particulate concentration downwind. The distance in one test was 50 feet downwind from the source and in the other test it was approximately 328 feet downwind. Because of the lack of background information concerning the moisture content of the rock processed, the operating conditions during the testing, and the distances from the source, these EFs were given only a C-rating. For a more detailed discussion and critique of the B- and C-rated tests see Appendix A.

3.1.2 Secondary Crushing Operations

The uncontrolled emission test data for secondary crushing operations are shown in Table 3-3. Average EFs and the test ratings along with process parameters are presented. There are two A-rated EFs, six B-rated EFs, and five C-rated EFs. All of the A-rated EFs are based on measurements taken in the inlet streams to a control device.

The B-rated EFs were calculated using the same methodology used for primary crushing operations (see Section 3.1.1). The C-rated EFs, while estimated using the same methodology used for primary crushing operations, were based on measurements made at distances ranging from 60 to 1,280 feet. For a more detailed discussion of the B- and C-rated tests, see Appendix A.

TABLE 3-3. SECONDARY CRUSHING OPERATION UNCONTROLLED EMISSION TESTS

	Average emission rate (lb/ton)	Test rating	Range of test data (lb/ton)	Emissions <2.5 microns (lb/ton)	Emissions <10 microns (lb/ton)	Company name/data source	Location of measurement device	Number of runs	Process Conditions: Average production (tons/hr)	Process Conditions: Average moisture content	Process Conditions: Type of rock	Average flow rate (acfm)	Particle size-D_{50} (microns)
1.	0.60	A	0.0006-1.2			J.M. Brenner (75-STN-7)	Baghouse Inlet	2	123	0.5	Limestone	7,540	--
2.	0.088	A	0.061-0.139	0.002	0.02	Cypress Bagdad (79-MET-4)	Scrubber Inlet	3	210	--	Quartz-monzonite rock	2,113	>10
3.	0.0003	C	--		0.0002	Crushed Limestone (EPA 600/2-78-004E)	60 Feet Downwind	1	364	--	Limestone	--	3.5
4.	0.0014	C			0.0006	Crushed Stone (EPA 600/2-78-004L)	400 Feet Downwind	1	600	--	Traprock	--	3.5
	0.0011	C	0.0008-0.0014		0.0007	Crushed Stone (EPA 600/2-78-004L)	230 Feet Downwind	2	710	--	Traprock	--	3.5
5.	0.045	C	0.031-0.065		0.002	Crushed Granite (EPA 600/2-78-021)	240 to 1,280 Feet Downwind	2	475	--	Granite	--	3.5
	0.015	C			0.001	Crushed Granite (EPA 600/2-78-021)	200 to 525 Feet Downwind	1	650	--	Granite	--	3.5
6.	0.0006	B			0.001	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	6	--	--	Traprock		3.5
	0.0002	B			0.0001	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	3	--	--	Limestone (1)		3.5
	0.088	B			0.064	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	12	--	--	Limestone (3)		3.5
	--	B			0.02	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	11	--	--	Granite		3.5
	--	B			0.002	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	15	--	--	Sand and Gravel (1)		3.5
	--	B			0.002	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet	12	--	--	Sand and Gravel (2)		3.5

3.1.3 Tertiary Crushing Operations

The uncontrolled emissions test data for tertiary crushing operations are shown in Table 3-4. Average EFs and the test ratings along with process parameters are presented. There is one A-rated EF, three B-rated EFs, and one C-rated EF. For a detailed discussion of the B- and C-rated tests, see Appendix A.

3.1.4 Dry Grinding and Fines Crushing Operations

The uncontrolled emissions tests data for dry grinding and fines crushing operations are shown in Table 3-5. Average EFs and the test ratings along with process parameters are presented. There are three A-rated EFs, two B-rated EFs, and two C-rated EFs. The testing methodologies employed is the same as those for the A-, B-, and C-rated tests of primary crushing operations (see Section 3.1.1). For a detailed discussion of the B- and C-rated tests, see Appendix A.

3.2 CONTROLLED EMISSIONS

The controlled emissions test data for all processing operations are shown in Table 3-6. All of the A-rated EFs are based on measurements in the control device's outlet stack. The B-rated EFs were estimated using the same methodology of the B-rated tests described in Section 3.1.1.

TABLE 3-4. TERTIARY CRUSHING OPERATION UNCONTROLLED EMISSION TESTS

	Average emission rate (lb/ton)	Test rating	Range of test data (lb/ton)	Emissions <2.5 microns (lb/ton)	Emissions <10 microns (lb/ton)	Company name/data source	Location of measurement device	Number of runs	Process Conditions: Average production (tons/hr)	Process Conditions: Average moisture content	Process Conditions: Type of rock	Average flow rate (acfm)	Particle size-D_{50} (microns)
1.	2.76	A	1.62-3.34	--	--	New Jersey Zinc (80-MET-6)	Baghouse Inlet	3	19	0.2	Franklinite Willemite Zincite	365	--
2.	0.0007	C	--	--	0.0001	Crushed Stone (EPA 600/2-78-004L)	400 Feet Downwind	1	695		Traprock	--	3.5
3.	0.0016	B	--	--	0.0008	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	6	--	--	Traprock	--	3.5
	0.0070	B	--	--	0.0060	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet	9	--	--	Limestone (3)	--	3.5
	--	B	--	--	0.08	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet	3	--	--	Granite	--	3.5

TABLE 3-5. DRY GRINDING AND FINES CRUSHING OPERATION UNCONTROLLED EMISSION TESTS

	Average emission rate (lb/ton)	Test rating	Range of test data (lb/ton)	Emissions <2.5 microns (lb/ton)	Emissions <10 microns (lb/ton)	Company name/data source	Location of measurement device	Number of runs	Average production (tons/hr)	Average mois-ture content	Type of rock	Average flow rate (acfm)	Particle size-D50 (microns)
1.	0.0003	C	--	--	--	Crushed Stone (EPA 600/2-78-004L)	400 Feet Downwind	1	600	--	Traprock	--	--
	0.00008	C	--	--	0.00003	Crushed Stone (EPA 600/2-78-004L)	425 Feet Downwind	1	695	--	Traprock	--	3.5
2.	0.0016	B	--	--	0.0014	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	6	--	--	Traprock	--	3.5
	--	B	--	--	0.008	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	30 Feet Downwind	8	--	--	Granite	--	3.5
3.	32.5	A	--	--	26.7	Engelhard Minerals (78-NMM-6)	Baghouse Inlet	1	3	--	Fuller's Earth	2,560	7.0
	37.1	A	--	--	36.4	Engelhard Minerals (78-NMM-6)	Baghouse Inlet	1	0.42	--	Fuller's Earth	2,060	1.5
4.	17.0	A	--	--	8.5	Union Carbide Hot Springs (80-MET-5)	Baghouse Inlet	1	67	--	Mixture of igneous rock complexes with sedimentary (clay) intru-sions	12,900	10

TABLE 3-6. PROCESSING OPERATIONS (CONTROLLED EMISSIONS)

Average emission rate (lb/ton)	Test rating	Range of test data (lb/ton)	Company name/data source	Control technique	Location of measurement device	Number of runs	Average production (tons/hr)	Type of rock
Primary Crushing								
0.0011	A	0.0009-0.0014	Arizona Portland Cement (74-STN-1)	Baghouse	Baghouse Outlet	3	1,011	Limestone
0.0011	A	0.0008-0.0014	Exxon Minerals Company (79-MET-1)	Scrubber	Scrubber Outlet	3	391	Tertiary Fluvial Sandstones
0.002	A	0.002-0.002	Anaconda Copper (79-MET-3)	Baghouse	Baghouse Outlet	3	2,118	Chalcocite Chalcopyrite Enargite Borxite
Secondary Crushing								
0.0003	A	0.0002-0.0004	Arizona Portland Cement (74-STN-1)	Baghouse	Baghouse Outlet	3	163	Limestone
0.007	A	0.004-0.009	Cypress Bagdad Copper (79-MET-4)	Scrubber	Scrubber Outlet	3	475	Quartz-Monzonite Rock
0.008	A	0.005-0.010	Homestake Mining (80-MET-7)	Baghouse	Baghouse Outlet	3	124	Cummingtonite Sideroplesite Vein Quartz Minor Sulfides
0.015	B	---	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	Wet Suppression	30 Feet Downwind	6	--	Limestone
Tertiary Crushing								
0.0055	A	0.0048-0.0067	Ferrante and Sons (75-STN-6)	Baghouse	Baghouse Outlet	3	395	Traprock
0.0016	B	---	Particulate Emissions from Stone Crushing Operations (Monsanto/TRC)	Wet Suppression	30 Feet Downwind	6	--	Limestone

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TABLE 3-6. (continued)

Average emission rate (lb/ton)	Test rating	Range of test data (lb/ton)	Company name/data source	Control technique	Location of measurement device	Number of runs	Average production (tons/hr)	Type of rock
<u>Dry Grinding</u>								
0.01	A	0.007-0.013	Englehard Minerals (78-NMM-6)	Baghouse	Baghouse Outlet	3	3	Fuller's Earth
0.07	A	0.047-0.095	Englehard Minerals (78-NMM-6)	Baghouse	Baghouse Outlet	3	0.42	Fuller's Earth
0.11	A	---	Union Carbide (80-MET-8)	Scrubber	Scrubber Outlet	1	70	Mixture of igneous rock complexes with sedimentary (clay) intrusions
<u>Primary and Secondary Crushing (combined)</u>								
0.0008	A	0.0004-0.001	J.M. Brenner (75-STN-7)	Baghouse	Baghouse Outlet	3	126	Limestone
<u>Tertiary Crushing and Dry Grinding (combined)</u>								
0.056	A	0.039-0.075	New Jersey Zinc (80-MET-6)	Baghouse	Baghouse Outlet	3	38	Franklinite Willemite Zincite

SECTION 4.0

DEVELOPMENT OF REPRESENTATIVE EMISSION FACTORS

The final objective of this report is to develop a representative EF value for each process fugitive source of particulate emissions in the construction aggregate industry. Section 3.0 presents all the available EF data. It is from the data in Section 3.0 that the representative EF values were developed.

4.1 TOTAL PROCESS FUGITIVE EMISSIONS

Table 4-1 shows a summary of the EFs by source and reliability rating. (The rating system was defined in Section 3.0). Recalling that the EFs are based on different numbers of test runs, the average of the test series average values as presented in Table 4.1 was calculated as follows:

$$EF\ avg = \sum_{i=1}^{i=T} EF_i \ N_i / \sum_{i=1}^{i=T} N_i$$

EF_i = average of test series i,

N_i = number of runs in test series i (if $N_i > 3$, then set $N_i = 3$),

T = number of test series, and

EF avg = emission factor average for a specific reliability rating category.

The philosophy behind the equation is that within the same rating category the test series composed of the most runs should receive the most weight. However, a limit to the weighting is set at a value of 3. This is to eliminate the possibility that a very high number of test performed at a very dirty or very clean, and consequently nonrepresentative, plant could unfairly weight the overall average. The value 3 was selected as the cutoff point for weighting averages of test series averages because

TABLE 4-1. SELECTION OF SINGLE EMISSION FACTOR VALUES FOR SOURCES IN THE CONSTRUCTION AGGREGATE INDUSTRY

Source	Test Series				Average EF for rating category	Calculated Single EF Value		
	Rating	Average EF (EFi)	EF units	Number of runs		Average	Range	Rating
PRIMARY CRUSHING								
Uncontrolled								
Dry	A	0.017	lb/ton	2	0.508	0.341	0.0015-0.686	B
	A	0.686	lb/ton	3				
	A	0.658	lb/ton	3				
	B	0.0015	lb/ton	6	0.0015			
	C	0.0011	lb/ton	Assume 1	0.0011			
Wet	A	0.041	lb/ton	3	0.0264	0.0264	0.0014-0.041	A
	A	0.0014	lb/ton	3				
	A	0.034	lb/ton	3				
Controlled								
Ducted to control device	A	0.0011	lb/ton	3	0.0014	0.0014	0.0011-0.002	A
	A	0.0011	lb/ton	3				
	A	0.002	lb/ton	3				
SECONDARY CRUSHING								
Uncontrolled	A	0.60	lb/ton	2	0.2928	0.21	0.0002-0.60	B
	A	0.088	lb/ton	3				
	B	0.0006	lb/ton	6	0.0296			
	B	0.0002	lb/ton	3				
	B	0.088	lb/ton	12				
	C	0.0003	lb/ton	Assume 1	0.0156			
	C	0.0014	lb/ton	Assume 1				
	C	0.0011	lb/ton	2				
	C	0.045	lb/ton	2				
	C	0.015	lb/ton	Assume 1				
Controlled								
Ducted to control device	A	0.0003	lb/ton	3	0.0051	0.0051	0.0003-0.008	A
	A	0.007	lb/ton	3				
	A	0.008	lb/ton	3				
Wet suppression	B	0.015	lb/ton	6	0.015	0.015	--	B

CONTINUED

TABLE 4-1. (continued)

Source	Test Series				Average EF for rating category	Calculated Single EF Value		
	Rating	Average EF (EFi)	EF units	Number of runs		Average	Range	Rating
TERTIARY CRUSHING								
Uncontrolled	A	2.76	lb/ton	3	2.76	1.85	0.0016-2.76	B
	B	0.0016	lb/ton	6	0.0043			
	B	0.0070	lb/ton	9				
	C	0.0007	lb/ton	Assume 1	0.0007			
Controlled								
Ducted to control device	A	0.0055	lb/ton	3	0.0055	0.0055	--	A
Wet suppression	B	0.0016	lb/ton	6	0.0016	0.0016	--	B
DRY GRINDING								
Uncontrolled	A	32.5	lb/ton	1	28.87	19.34	0.0016-37.1	B
	A	37.1	lb/ton	1				
	A	17.0	lb/ton	1				
	B	0.0016	lb/ton	6				
	C	0.0003	lb/ton	Assume 1	0.0016			
	C	0.00008	lb/ton	Assume 1	0.00019			
Controlled								
Ducted to control device	A	0.01	lb/ton	3	0.05	0.05	0.01-0.11	A
	A	0.07	lb/ton	3				
	A	0.11	lb/ton	1				

of the unwritten rule generally followed by EPA that 3 tests are sufficient to quantify emissions from a source.

The rules for calculating the representative EF for a source are: .

1. If any source category has four or more A-rated test series, then the representative EF value shall be equal to the average of these A-rated test series as determined by Equation 1.

2. If any source category has less than four A-rated test series but more than zero, then the representative EF value shall be a weighted average of the A- and B-rated averages with the A-rated EF average receiving twice the weight that the B-rated EF average does.

3. If there are no A-rated values, then the representative EF value shall be equal to the average of the B-rated test series averages as determined by the equation.

If there are no A- and B-rated values, then the representative EF value shall be equal to the average of C- and D-rated values.

The philosophy behind the above rules is as follows. If there is a significant number of A-rated test series, that is, tests performed by a sound methodology and reported in enough detail to adequately validate the test series, then the single value should be set equal to the average of the A-rated values alone. If there are not enough A-rated test series to cover a significant number of plants (estimated as four), then the B-rated test series should also be included in the averaging process so that the single EF value approaches a true industry-wide average. But, in order to counter-balance the fact that B-rated test series may not have been performed properly, the A-rated average should be weighted as more important than (twice as heavily as) the B-rated average. If there are no A-rated test series, then the single value should be set equal to the average of the B-rated test series. No C- or D-rated test series should be included with A- or B-rated tests in determining the single EF, because they were performed by either an untested or unacceptable methodology or lack sufficient background information. If there are no A- or B-rated test series, then the single EF value should be set equal to the average of the C- and D-rated test series. This provides at least an order of magnitude value for the source, but should by no means be expected to provide any more precision. These C- and D-rated test series are only used as a last resort since no other data are available.

4.2 PROCESS FUGITIVE EMISSIONS LESS THAN 10 MICRONS

Table 4-2 shows a summary of the EFs by source and reliability rating. These EFs are for particulate emissions less than 10 microns in size. The methodology used in determining the single EF values for each source is the same methodology described in Section 4.1.

TABLE 4-2. SELECTION OF SINGLE EMISSION FACTOR VALUES FOR SOURCES IN THE CONSTRUCTION AGGREGATE INDUSTRY (LESS THAN 10 MICRONS)

Source	Test Series				Average EF for rating category	Calculated Single EF Value		
	Rating	Average EF (EFi)	EF units	Number of runs		Average	Range	Rating
PRIMARY CRUSHING								
Uncontrolled	A	0.046	lb/ton	3	0.016	0.016	0.0012-0.046	A
	A	0.016	lb/ton	3				
	A	0.0012	lb/ton	3				
	A	0.0015	lb/ton	3				
	B	0.0008	lb/ton	6	0.003			
	B	0.01	lb/ton	6				
	B	0.0006	lb/ton	9				
	B	0.001	lb/ton	10				
	C	0.0003	lb/ton	Assume 1	0.001			
	C	0.003	lb/ton	Assume 1				
SECONDARY CRUSHING								
Uncontrolled	A	0.02	lb/ton	3	0.02	0.0184	0.0001-0.064	B
	B	0.001	lb/ton	6	0.015			
	B	0.0001	lb/ton	3				
	B	0.064	lb/ton	12				
	B	0.02	lb/ton	11				
	B	0.002	lb/ton	15				
	B	0.002	lb/ton	12				
	C	0.0002	lb/ton	Assume 1	0.001			
	C	0.0006	lb/ton	Assume 1				
	C	0.0007	lb/ton	2				
	C	0.002	lb/ton	2				
	C	0.001	lb/ton	Assume 1				
TERTIARY CRUSHING	A	0.36	lb/ton	3	0.36	0.25	0.0008-0.36	B
	B	0.0008	lb/ton	6	0.029			
	B	0.006	lb/ton	9				
	B	0.08	lb/ton	23				
	C	0.0001	lb/ton	Assume 1	0.0001			
DRY GRINDING	A	26.7	lb/ton	1	23.9	16.0	0.0014-36.4	B
	A	36.4	lb/ton	1				
	A	8.5	lb/ton	1				
	B	0.0014	lb/ton	6				
	B	0.008	lb/ton	8				
	C	0.00003	lb/ton	Assume 1	0.00003			

APPENDIX A
EMISSION TEST REVIEW

This Appendix contains detailed reviews of all of the B- and C- rated particulate emission tests used in this report.

EMISSION TEST REVIEW

Source Assessment: Crushed Limestone, State of the Art
EPA-600/2-78-004E

Methodology

Two crushed limestone plants were chosen whose operations were considered representative of the crushed limestone industry. Total and respirable ambient particulate concentraions (or dosages) were measured downwind from unit operations and emission rates calculated by means of dispersion models. A point source model was used for all operations except conveying and hauling on unpaved roads for which a line source model was employed. Different unit operations were tested at the two plants and then combined to provide a table of emission factors for a representative plant.

Sampling Equipment

A single GCA dust monitor (presumably Model RDM 101-4) was used to measure respirable and total particulate concentrations from unit processing operations.

Plants Tested

Mining operations at the two crushed limestone facilities were similar. Processing at the two plants differed somewhat in the types of crushing and screening operations and in the mesh sizes of the screens used. The limestone is processed into the following three sizes at each plant: Plant A - 19-44 mm; 6-19 mm, and $<$6 mm; Plant B - 19-50 mm, 13-19 mm, and $<$13 mm. Approximate processing rates through the primary crushers of plants A and B were 190 and 330 metric tons/hour.

Data Base

The number of trials completed for various operations at each plant are given in Table 1.

Table 1. Number of Trials at each Plant

Unit Operation	Number of Trials			
	Plant A		Plant B	
	Total	Respirable	Total	Respirable
Blasting		1		
Drilling		2		
Front-End Loading	1			
Primary Crushing	1	1		
Primary Screening		1		
Secondary Crushing			1	2
Belt Conveyors				1
Secondary Screening				2
Unpaved Road				3

Emission Factors

Table 2 lists the emission factors that were determined for unit operations at the two plants. When data were available for two or more trials for an operation, the range covered by the values is also given. Table 3 lists the emission factors for the various unit operations that were summed to provide a factor for an entire crushed stone facility.

Comments and Points Needing Clarification

The number of observations used to obtain each estimate of emission rate in Tables B-4 and B-5 is not specified. This may mean that each Q value was determined from a single sample, usually of 4 minutes duration. If this is so, the data base is too limited to do more than suggest the order of magnitude of the emission factors. The data for total particulates is particularly limited, with only three of the operations having been sampled.

No allowance appears to have been made for actual source dimensions in applying the point source model. For example, in calculating emissions from front-end loading at Plant A, σ_z at a distance of 20 feet (6.1 meters) is assumed to be only 0.39 meters whereas the cloud created by the loading operation probably was several meters high right at the source. Since Q was calculated from the equation

$$Q = \pi \sigma_y \sigma_z \bar{u} \chi$$

underestimating either σ_y or σ_z results in a corresponding underestimate of Q.

As in EPA-600/2-78-004L, more sampling details would be helpful. For example: On how many days was sampling carried out and at what times of day? How many background measurements were made, how did they vary, and how

Table 2. Calculated Emission Factors at Each Plant

Unit Operation	Emission Factor - Average and Range (g/metric ton)					
	Plant A			Plant B		
	Average	Low	High	Average	Low	High
	Total Particulates					
Blasting	-	-	-	-	-	-
Drilling	-	-	-	-	-	-
Front-End Loading	0.0015	-	-	-	-	-
Primary Crushing	0.560	-	-	-	-	-
Primary Screening	-	-	-	-	-	-
Secondary Crushing	-	-	-	0.144	-	-
Belt Conveyors	-	-	-	-	-	-
Secondary Screening	-	-	-	-	-	-
Unpaved Road	-	-	-	-	-	-
	Respirable Particulates					
Blasting	0.013	-	-	-	-	-
Drilling	0.011	0.006	0.016	-	-	-
Front-End Loading	-	-	-	-	-	-
Primary Crushing	0.166	-	-	-	-	-
Primary Screening	0.0005	-	-	-	-	-
Secondary Crushing	-	-	-	0.077	0.035	0.118
Belt Conveyors	-	-	-	0.096	-	-
Secondary Screening	-	-	-	0.0005	0.0002	0.0007
Unpaved Road	-	-	-	0.230	0.168	0.315

Table 3. Unit-Operation Emission Factors Used in Developing Factors for Representative Crushed Limestone Facility. (from Table B-6 of EPA report)

Unit Operation	Emission Factor (g/metric ton)	
	Total Particulates	Respirable Particulates
Blasting	0.075E	0.013
Drilling	0.110E	0.011
Front-End Loading	0.0015	0.000E
Primary Crushing	0.560	0.166
Primary Screening	0.0016E	0.0005
Secondary Crushing	0.144	0.077
Belt Conveyors	0.320E	0.096
Secondary Screening	0.0009E	0.0005
Unpaved Road	2.30E	0.230
TOTAL	3.513	0.594

Notes: (1) E indicates a value estimated by assuming a relationship between the amounts of total and respirable particulates determined from other experiments. Assumed relationships range from 10 to 53 percent respirable.

(2) Emissions from wind erosion of stockpiles and unloading at stockpiles are assumed to be negligible.

did the time schedule of background measurements fit in with the schedule of the other measurements? What does it mean when Y = 0 in Tables B-4 and B-5? (i.e. Was it simply assumed that the sample was collected on the plume axis?).

EMISSION TEST REVIEW

Source Assessment: Crushed Stone EPA-600/2-78-004L

Methodology

The general approach was to select two crushed traprock facilities whose operations were considered representative of the crushed stone industry. Total and respirable ambient particulate concentrations (or dosages) were measured downwind from unit operations and emission rates (or total emissions) calculated by means of dispersion models. Emission factors for each operation were developed from the results and plant operating parameters. Factors from the two plants were then averaged and the averages used to obtain emission factors for total and respirable particulates for an entire facility. These factors were assumed to apply to a representative plant with a production rate of 454 metric tons/hr.

Sampling Equipment

Five high-volume samplers equipped with Nuclepore membrane filters were used to sample quarrying activities. A single GCA Model RDM 101-4 dust monitor was used to measure respirable and total particulate concentrations from unit processing operations.

Plants Tested

Both of the crushed traprock facilities selected conducted similar blasting, quarrying, and primary crushing activities. Processing at the two plants differred somewhat in the number of crushing and screening operations and in the mesh sizes of the screens used. Approximate processing rates through the primary crushers of the two plants (A and B) were 545 and 645 metric tons/hour, respectively.

Data Base

The number of trials completed for various operations at each plant are given in Table 1.

Table 1. Number of Trials at Each Plant

Unit Operation	Number of Trials			
	Plant A		Plant B	
	Total	Respirable	Total	Respirable
Blasting	-	-	1	1
Drilling	-	-	-	-
Quarrying	2	-	-	-
Primary Crushing & Unloading	-	1	-	-
Secondary Crushing & Screening	1	2	2	2
Tertiary Crushing & Screening	-	-	1	1
Fines Crushing & Screening	1	-	1	1
Conveying	1	1	-	-
Unloading of Trucks	3	1	4	5
Loading of Trucks	1	1	1	1

Emission Factors

Table 2 lists the emission factors that were determined for unit operations at the two plants. When data were available for two or more trials for an operation, the range covered by the values is also given. Table 3 lists the emission factors for the various unit operations that were summed to provide a factor for an entire crushed stone facility.

Table 2. Calculated Emission Factors at Each Plant

Unit Operation	Emission Factor - Average and Range (g/metric ton)					
	Plant A			Plant B		
	Average	Low	High	Average	Low	High
	Total Particulates					
Blasting	-	-	-	0.052	-	-
Drilling	-	-	-	-	-	-
Quarrying	10.56	10.54	10.58	-	-	-
Primary Crushing & Unloading	-	-	-	-	-	-
Secondary Crushing & Screening	0.698	-	-	0.542	0.390	0.693
Tertiary Crushing & Screening	-	-	-	0.362	-	-
Fines Crushing & Screening	0.144	-	-	0.040	-	-
Conveying	1.733	-	-	-	-	-
Unloading of Trucks	0.048	0.013	0.093	0.208	0.014	0.679
Loading of Trucks	0.106	-	-	0.224	-	-
	Respirable Particulates					
Blasting	-	-	-	0.009	-	-
Drilling	-	-	-	-	-	-
Quarrying	-	-	-	-	-	-
Primary Crushing & Unloading	1.34	-	-	-	-	-
Secondary Crushing & Screening	0.316	0.279	0.353	0.368	0.185	0.551
Tertiary Crushing & Screening	-	-	-	0.066	-	-
Fines Crushing & Screening	-	-	-	0.015	-	-
Conveying	0.113	-	-	-	-	-
Unloading of Trucks	0.033	-	-	0.074	0.006	0.250
Loading of Trucks	0.010	-	-	0.081	-	-

Table 3. Unit-Operation Emission Factors Used in Developing Factors for Representative Crushed Stone Facility. (from Table 3 of EPA report)

Unit Operation	Emission Factor (g/metric ton)	
	Total Particulates	Respirable Particulates
Blasting	0.052	0.009
Drilling	0.158	0.016E
Quarrying	10.500	1.050E
Primary Crushing & Unloading	13.400E	1.340
Secondary Crushing & Screening	0.619	0.342
Tertiary Crushing & Screening	0.362	0.066
Fines Crushing & Screening	0.092	0.015
Conveying	1.730	0.113
Unloading of Trucks	0.127	0.054
Loading of Trucks	0.166	0.045
Wet Unpaved Road	1.150	0.202
TOTAL	28.356	3.252

Notes: (1) E indicates a value estimated by assuming that 10% of total suspended particulates are respirable

(2) Emission factor for total particulates from drilling was obtained from a study of crushed granite operations.

Comments and Points Needing Clarification

- The number of observations actually used to obtain each estimate of emission rate (or dosage) is not provided in the report. Is each Q listed in Tables C-1 and C-2 based on a single measurement of concentration or dosage, or is each Q the average of several measurements? If more that one measurement was used in obtaining a Q, how many were used in each case and how was the averaging accomplished?

- All Y's in Tables C-1 and C-2 are 0.0. Does this mean that the observed concentrations were always assumed to be on the plume axis, or were axial values calculated and reported in the tables?

- On how many different days was sampling carried out at each plant? Over what time period?

- All unit operation measurements appear to have been made with one RDM. How many measurements of background concentration were made and how variable were they?

- Are the processing rates for Plants A and B 545 and 645 metric tons/hour, respectively, as given on pages 59 and 61, or 533 and 631 metric tons/hour as stated on pages 63 and 64?

- How was determined for the line source dosage equation on page 65?

I have two general comments. First, although the methodology appears to be sound, details of the measurement program and calculations are not provided. Furthermore, even the summary tables (Tables C-1 and C-2) lack such basic information as whether a trial measured respirable or total particulates, and the number of individual observations that went into the calculation of each Q estimate. The reader is left to assume that the field trials and the calculations were carried out correctly.

My second comment is directed toward the size of the data base. Although confidence limits have been placed on the emission factor estimates for an entire facility it is not clear how these limits were obtained. It is clear from Tables 1 and 2, however, that the data are limited, even for the two plants that were tested, and that in the few cases in which measurements were made downwind of the same unit operation at both plants, differences in average values between the plants were sometimes great. The uncertainty in the data is also evident from Table 3. If I have followed the report correctly, nearly one-half of the emissions of total particulates is believed to come from the primary crushing and unloading operation (13.4 g/metric ton). However, this estimate is based on a single trial at Plant A during which only respirable particulates were measured. It was assumed that the concentration of total particulates during this trial would have been 10 times as great. Similarly, the second highest value for respirable particulates (quarrying, 1.05 g/metric ton) results not from measurements of respirable concentrations but from two trials in which total particulates were measured at Plant A.

EMISSION TEST REVIEW

Emissions from the Crushed Granite Industry: State of the Art
EPA-600/2-78-021

Methodology

Field measurements of emissions were made only when estimates could not be obtained for similar operations from the literature. Two crushed granite plants were selected for monitoring that were considered representative of the crushed granite industry. Total and respirable ambient particulate concentrations (or dosages) were measured downwind from unit operations and emission rates calculated by means of dispersion models. Emission factors for each operation were developed from the results and plant operating parameters. Data from the two plants and from the literature were combined to obtain emission factors for an entire facility.

Sampling Equipment

A single GCA dust monitor (presumably Model RDM 101-4) was used to measure concentrations of total and respirable particulates; other observations of total particulate concentrations were made by standard high-volume samplers. In principle, the RDM was used to measure emissions from small unit operations and hi-vols for area wide emissions.

Plants Tested

Operations at the two plants were conducted somewhat differently. At Plant A, the quarry operations (drilling and blasting) and the primary crushing take place in a pit and were said to make only minor contributions to overall plant emissions. After passing through the secondary crusher cone, the material is fed by a conveyor to a screen tower where it falls into a bin. From the bin, it is loaded into railroad cars or trucks for delivery either to customers or to a stockpile.

At Plant B, the blasted material is loaded by shovel into trucks to be hauled and dumped into a jaw crusher. It is then processed through two scalping screens and cone crushers and transferred by a belt conveyor to a secondary plant where it is sized and fed into blending tunnels. From the blender, it is either trucked to customers or to storage, or loaded into railroad cases. The fine crushings are fed to two cone crushers and transferred to a sand plant.

Water is applied to the haul roads from the quarry area to the plant at Plant A. Wet screening operations are used at Plant B.

Data Base

The number of trials completed for various operations at each plant are given in Table 1.

Table 1. Number of Trials at Each Plant

Unit Operation	Number of Trials			
	Plant A		Plant B	
	Total	Respirable	Total	Respirable
Drilling (wet)	-	-	4	2
(dry)	-	1	-	-
Blasting	1	-	-	-
Secondary crushing only	-	-	-	8
Secondary crushing and screening	8	-	-	-
Dumping to primary crusher	-	2	-	-
Overall plant emission	-	-	4	-

Emission Factors

Table 2 lists the emission factors that were determined from measurements made at the two plants. Several of these factors were estimated by combining information from tests at different plants as explained in the notes at the foot of the table.

Table 3 contains the emission factors that were used in developing the factor for a representative curshed granite facility.

Table 2. Calculated Emission Factors at the Two Plants

Unit Operation	Emission Factor - Average and Range (g/metric ton)					
	Plant A			Plant B		
	Average	Low	High	Average	Low	High
	Total Particulates					
Drilling (wet)[1]	0.399	0.179	0.573	-	-	-
(dry)	-	-	-	-	-	-
Blasting	79.6	-	-	-	-	-
Secondary crushing and screening	22.4	15.7	32.6	-	-	-
Secondary crushing only	-	-	-	7.6[4]	-	-
Secondary screening only	14.4[5]	-	-	-	-	-
Dumping to primary crusher	0.21[6]	-	-	-	-	-
Vehicular movement on unpaved roads	-	-	-	4.91	-	-
	Respirable Particulates					
Drilling (wet)[1]	0.040	0.038	0.042	-	-	-
(dry)[1]	9.477	-	-	-	-	-
Blasting	13.5[2]	-	-	-	-	-
Secondary crushing & screening	0.858[3]	-	-	-	-	-
Secondary crushing only	-	-	-	0.295	0.180	0.403
Secondary screening only	-	-	-	-	-	-
Dumping to primary crusher	0.008	-	-	-	-	-
Vehicular movement on unpaved roads	-	-	-	0.864[7]	-	-

Notes: 1. Emission factors have been determined from emission rates measured at Plant B and average production rate at Plant A

2. Calculated from total emissions and an R/T ratio of 0.169 determined from crushed stone operations

3. Calculated by applying an R/T ratio of 0.036 obtained from secondary crushing respirable measurements and overall plant total measurements at Plant B to secondary crushing and screening total measurements at Plant A.

4. Calculated from secondary crushing respirable measurements and an R/T ratio of 0.039 (why not 0.036 as in Note 3?)

5. Calculated by subtracting secondary crushing emission rate at Plant B (7.6g/metric ton) from secondary crushing and screening emission rate at Plant A (22.4g/metric ton)

6. Calculated by applying an R/T ratio of 0.036 to respirable measurements.

7. Calculated by subtracting average emission rate measured during secondary crushing when no trucks were passing from the emission rate measured when one truck passed.

8. Calculated by applying an R/T ratio of 0.176 determined from crushed stone operations to respirable data

Table 3: Unit-Operation Emission Factors Used in Developing Factors for a Representative Crushed Granite Facility (taken from Table 1 of the EPA report)

	Emission Factor (g/metric ton)	
Unit Operation	Total Particulates	Respirable Particulates
Drilling (wet)	0.399	0.040
Blasting	79.6	13.5
Dumping to primary crusher	0.21	0.008
Secondary crushing & screening	22.4	0.858
Vehicular movement on dry unpaved roads	4.91	0.864
TOTAL	107.519	15.270

Other Comments and Points Needing Clarification

Points needing clarification concerning sampling procedures and methodology have already been discussed in the reviews of other documents prepared by Monsanto and won't be repeated here.

This is a "State of the Art" document and an attempt is made to deduce an emission factor from very limited data and reasonable assumptions. A number of operations listed in Table 1 of the EPA report* are assumed to have negligible emissions, but there is no supporting evidence for this assumption. Approximately 74 percent of the emissions listed come from blasting and 21 percent from secondary crushing and screening. The very large amount that is calculated to come from blasting at Plant A does not appear to agree with the statement on p. 31 describing operations at Plant A which says "The quarry operations and primary crushing take place in a pit and hence are only minor contributors to the overall plant emissions."

Again, there appear to be a number of small arithmetic errors, but none of these influence the conclusions significantly.

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* These operations include loading onto haul trucks, primary crusher, conveying, unloading to stockpiles, loading from stockpiles, and windblown emissions.

EMISSION TEST REVIEW

An Investigation of Particulate Emissions from Construction Aggregate Crushing Operations and Related New Source Performance Standards. Prepared by: National Crushed Stone Association, National Industrial Sand Association, Associated General Contractors of America, and the National Sand and Gravel Association.

(This report is comprised of four sections. Sections 2 and 3 discuss the techniques used to obtain emission factors and present the results. Section 2, "Particulate Emissions from Stone Crushing Operations" was prepared by Monsanto Research Corporation. Section 3, "Source Measurements, Crushed Stone - Sand and Gravel Plants" was prepared by TRC - Denver. This review covers the work presented in these two sections.)

Methodology

Emission rates were measured by the following technique. A tracer gas (SF_6) was released at a constant rate near the source of particulates, and in a manner which closely simulated the particulate source. For each crusher tested, the tracer gas was injected into the input stream to the crusher. As a result of this procedure, it was assumed that the tracer gas was well mixed with the dust cloud emitted from the crusher and that its rate of diffusion was identical to that of the fine particles within the cloud. Concentrations of particulate and tracer were then measured at downwind distances ranging from about 30 to 120 feet, and the source strength (emission rate) of particulates determined from the relationship

$$\frac{Q_D}{C_D} = \frac{Q_T}{C_T}$$

In this equation, Q and C are, respectively, the emission rate and downwind concentration, and the subscripts D and T refer, respectively, to the particulate (dust) and tracer gas. Thus, Q_D can be calculated directly from field measurements of Q_T, C_D and C_T without the use of dispersion equations.

Once the emission rate of particulates was determined for a unit operation, its emission factor was calculated by dividing by the throughput rate. Thus,

$$\text{Emission Factor, g/kg} = \frac{\text{Emission rate } (Q_D)\text{, g/hr}}{\text{Throughput rate, kg/hr}}$$

Sampling and Tracer Release Equipment

A GCA dust monitor, Model RDM 101-4, was used to measure respirable and total particulate concentration. With the cyclone separator in place, only particles with an aerodynamic diameter less than 10 μm are collected and the 50 percent cut-point is at 3.5 μm. Without the cyclone separator, particles up to approximately 50 μm in diameter are collected.

The tracer gas was dispensed at a constant rate from a pre-weighed cylinder, and the emission rate calculated from the weight loss from the cylinder during the test period. Air samples were collected in Tedlar bags and analyzed for SF_6 with a gas chromatograph equipped with an electron capture detector.

Under the test conditions, the GCA dust monitor functioned best with a 4-minute sampling time, whereas the tracer samplers required 10 to 15 minutes to collect a large enough air sample for accurate analysis. To compensate for this difference, three consecutive dust samples were taken during each SF_6 sample. An SF_6 concentration was then calculated for each of the three dust sampling periods by distributing the measured SF_6 concentration in proportion to the three measured dust concentrations.

Plants Tested

A total of 287 mass concentration measurements were made downwind from 16 different stone crushing operations at 7 different plants. The units tested included 4 primary crushing operations, 7 secondary crushing operations, 3 tertiary crushing operations, and 2 fines milling operations. These crushing operations were distributed among 1 granite plant, 2 sand and gravel plants, 1 traprock plant, and 3 limestone plants.

Data Base

The number of successful tests conducted for each crusher and plant are not provided in the body of the report. The work sheets included as Appendix D indicate fairly uniform distribution among the unit operations tested, however. Most of the particulate measurements were made with the cyclone separator on the RDM and hence comprised only the respirable fraction. Table 1 is an attempt to tally the number of respirable and total observations made at each unit operation from the data in Appendix D. One of the pages is missing and some of the copy is of poor quality, so the information in Table 2 may contain minor errors. Eight of the particulate observations were deleted, leaving a total of 279 to be entered in the table. The number of independent source estimates is approximately one-third of the number of particulate measurements as explained later under Comments.

Table 1. Number of Particulate Measurements at Various Crushing Operations

Plant and Stone Type	Primary		Secondary		Tertiary		Fines	
	Total	Res	Total	Res.	Total	Res	Total	Res.
A. Granite		16		11		23 (3)		8
B. Sand & gravel		9		15				
C. Sand & gravel		10		12				
D. Traprock	6	9	6	9	6	9	6	11
E. Limestone (1)				3	6 (4)	5 (4)		
F. Limestone (2)			13	13				
G. Limestone (1)								
- Uncontrolled			12	7	9	9		
- Controlled			6	12	6	12		

Notes: 1) Plant E uses a wet processing technique. Tests at Plant G were carried out with and without a wet dust suppression control system. Emissions during all other tests were uncontrolled.

2) No SF_6 Tracer trials were carried out at Plant F.

3) 12 values from the missing page have been included here

4) These tests are indicated as being influenced by both secondary and tertiary crushing operations

Emission Factors

Table 2 lists the emission factors that were determined as a result of the field trials. The emission factors have been taken directly from Tables 5 6 and 7 of the Monsanto report, however, the units have been changed from g/kg and 16/ton to g/metric ton to facilitate comparison with emission factor summaries submitted in previous report reviews. Emission factors for Plant G are presented for both uncontrolled and controlled operations.

Table 2. Calculated Emission Factors for Various Crushing Operations

Plant/Stone Type	Emission Factor - Average and Standard Deviation (g/metric ton)							
	Primary Crusher		Secondary Crusher		Tertiary Crusher		Fines Crusher	
	Avg.	Stan. Dev.	Avg.	Stan. Dev.	Avg.	Stan. Dev	Avg.	Stan Dev
			Total Particulates (< 50 um)					
A Granite	-	-	-	-	-	-	-	-
B Sand & gravel	-	-	-	-	-	-	-	-
C Sand & gravel	-	-	-	-	-	-	-	-
D Traprock	0.7	0.08	0.3	0.05	0.8	0.2	0.8	0.2
E Limestone	-	-	0.09	0.2	-	-	-	-
F Limestone	-	-	-	-	-	-	-	-
G Limestone-Uncontrolled	-	-	44.	40.	3.5	0.8	-	-
Controlled	-	-	7.5	-	0.8	-	-	-
			Respirable Particulates					
A Granite	5	0.2	10.	2	40	17	4	1
B Sand & gravel	3	0.15	1	0.1	-	-	-	-
C Sand & gravel	0.5	0.4	1	0.1	-	-	-	-
D Traprock	0.4	0.4	0.5	0.7	0.4	0.1	0.7	0.35
E Limestone	-	-	0.05	0.1	-	-	-	-
F Limestone	-	-	-	-	-	-	-	-
G Limestone-Uncontrolled	-	-	32.	10	3.	0.9	-	-
Controlled	-	-	2.4	-	0.55	-	-	-

Note: The tracer technique was not used at Plant F, so no emission factors were calculated.

Comments

The tracer technique used to determine emission rates in these field experiments is sound and, if carefully used, should result in more reliable estimates than those obtained by diffusion modeling.

A surprisingly large number of the trials appear to have been carried out under near calm or extremely light wind speeds. Of the 202 trials with recorded wind speed listed in my copy of the MRC report, 106 have a speed of 0.1 mph or less and only 9 have a speed of 5 mph or greater. Under near calm conditions, wind direction is usually highly variable and there is no well defined plume. Fine particulates generated by the plant operations are likely to drift around near the source for several minutes before leaving the area. Under these conditions, uncertainties in the emission rate estimates are likely to be introduced unless the release points for tracer and particulate are identical, and a sufficiently long tracer release time is used. It also makes the determination of an upwind background concentration of particulates questionable. Presumably the trials were run with sufficient care to minimize these sources of error, but I really can't tell from the reports.

Appendix B of the MRC report states that "three bag samplers were obtained at each downwind distance to observe the variance of SF_6 concentrations between bag samples." That certainly was a good idea and I was hoping to find the results in the report, but couldn't.

The reports assume that each particulate measurement resulted in an independent estimate of the emission rate, whereas the number of independent estimates is really determined by the number of tracer measurements. As explained above under Methodology, a trial consisted of 3 consecutive particulate measurements and a single SF_6 measurement bridging these three time periods. It is then assumed that the SF_6 concentration during each of the 3 consecutive time periods varied directly with the measured particulate concentration. Three dilution factors are calculated using this assumption and applied to the measured particulate concentrations. This results in 3 identical emission rates for the trial. (A simpler procedure, yielding an equivalent emission rate, would have been to use the average of the 3 particulate concentrations with the measured SF_6 data.)

The MRC report stresses the importance of the fallout of larger particles between the source and the property line. This is undoubtedly a very significant factor, however, these trials supply very little, if any, data to quantify this effect. The use of a single RDM 101-4 sampler (as apparently was the case) to measure both size fractions (i.e. $<$ 10μm and $<$50μm) means that the two fractions were measured at different times. Under the light wind conditions that prevailed for most of these trials, the concentration field can be expected to change significantly with time and any comparison of concentrations of the two size fractions from different time periods will be subject to great uncertainty. The data in Tables 1 and 2 used by MRD in its argument support this uncertainty. Note, in particular, that the average concentration of the $<$10μm particles (640μg/m^3) is greater than the average concentration of particles $<$ 50μm (420μg/m^3) at the primary crusher.

In considering the estimated emission rates for particles $<$10μm, one should bear the collection characteristics of the RDM-101 (shown in Figure 1) in mind. The instrument design and flow rate are such that the 50 percent, cutpoint is at 3.5μm. It can be seen from the curve that about 75 percent of particles 5μm in diameter are excluded from the sampler, and that nearly all particles greater than 8μm are excluded. On the average it can be expected that about 80 percent of particles in the range from 3.5 μm to 10 μm will not be collected by the RDM sampler. Thus the emission rates provided for particles $<$10 μm probably underestimate the real emission rates for suspended particles.

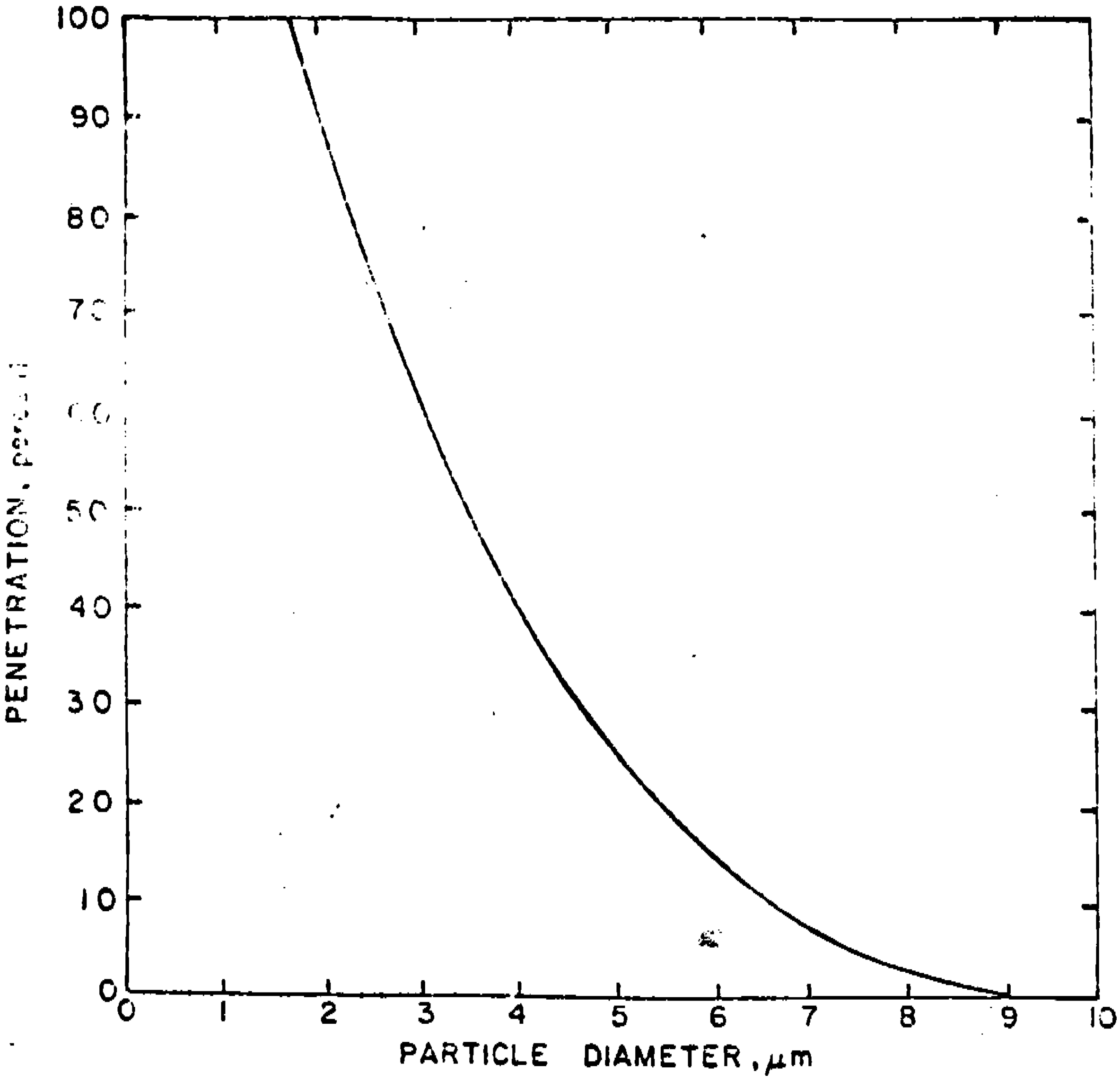

Figure 1. Penetration Characteristics of Cyclone Precollector.