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Source Assessment: Crushed Stone

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SOURCE ASSESSMENT: CRUSHED STONE

by

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TABLE 3. EMISSION FACTORS FOR CRUSHED STONE OPERATIONS

Unit operation	Respirable particulates, mg/metric ton	% of Total respirable particulates from all crushed stone operations	Total particulates, mg/metric ton	% of Total particulates from all crushed stone operations[a]	Respirable particulate, % of total particulates from unit operation
Blasting	8.8	0.27	52.2	0.18	17
Drilling (wet)	16.0	0.49	158	0.56	10
Quarrying	1,050	32.3	10,500	37.02	10
Primary crushing and unloading	1,340	41.2	13,400	47.2	10
Secondary crushing and screening	342	10.5	619	2.18	55
Tertiary crushing and screening	66.5	2.05	362	1.28	18
Fines crushing and screening	14.7	0.45	91.8	0.32	16
Conveying	113	3.48	1,730	6.10	7
Loading trucks	45.3	1.39	166	0.58	68
Unloading trucks	53.8	1.65	127	0.45	42
Transport (wet)	202	6.21	1,150	4.05	18
Total	3,250		28,400		11[b]

[a]Rounded off; does not add to 100%.

[b]Total respirable particulates as percent of total particulates from all unit operations.

APPENDIX C

SAMPLING RESULTS AND ERROR ANALYSIS

The purpose of sampling is to obtain an estimate of the overall plant emissions and also the relative contributions of the various unit operations. This appendix describes the sites that were selected for sampling, the results of the sampling effort, the emission factors determined, and an estimate of the error associated with the emission rate data.

Two crushed traprock facilities were chosen whose operations are representative of the crushed stone industry. Traprock accounts for 68% of total crushed stone production. Further, these plants were located in areas with meteorological conditions favorable for sampling.

1. SITE DESCRIPTION

a. Plant A

(1) Blasting and Drilling--
At the blasting site, holes are drilled in the rock in a square pattern, with water applied at the drill face. These holes are then charged with ANFO (ammonium nitrate and fuel oil) and dynamite, and the rock is blasted away.

(2) Quarrying--
A shovel and front-end loader dump blasted material onto haul trucks. The front-end loader is also used to reposition material that facilitated use of the shovel. Three trucks are used to haul the rock on an unpaved road to a hopper.

(3) Primary Crushing and Unloading--
Material is fed by gravity from the hopper into the primary crusher. This unit fragments the rock down to a top size of 150 mm to 180 mm (6 in. to 7 in.) in diameter. Crushed material is transferred via belt conveyor to a storage pile.

(4) Processing Activities--
The process begins with material conveyed from the stockpile generated by the primary crusher. This aggregate has a top size of 0.25 m (10 in.) and is transferred by tunnel belt conveyor to the first screen tower. Undersize material at the tower is gravity loaded into a bin that is periodically gravity unloaded

onto trucks. Oversize stone is either chute fed into a 2.1-m (7-ft) cone crusher which breaks the aggregate down to a top size of 0.1 m (3 to 4 in.), or belt conveyed by a stacker to a surge pile. Material from this pile is belt conveyed to the next screen tower where undersize material falls into the bin for unloading, and oversize material is crushed by a 1.7-m (5 1/2-ft) crusher to a top size of 44 mm (1 3/4 in.) and belt conveyed to a third screen tower. At this tower, undersize material is also bin fed to trucks. Oversize stone is crushed to a top size of 16 mm (5/8 in.) and belt conveyed to the conveyor feeding the screen for resizing.

Trucks loading at the screen stations are positioned under the bins and the bottom gates are opened, letting stone fall by gravity into the trucks. The stone is then transported on unpaved roads to the appropriate stockpile. Front-end loaders work in the area, smoothing the tops of the stockpiles and filling customer trucks that enter. These vehicles all travel on unpaved roads. A tank truck also circulates throughout this facility, spraying water on the roads for dust suppression.

The plant operates for about 4.5 hr/day, 2 days/wk. The processing rate through the primary crusher is about 545 metric tons/hour.

The sampling data and results are given in Table C-1.

b. Plant B

The blasting, quarrying, and primary crushing activities are similar to those at Plant A; hence, only the processing activities are described.

At the processing plant, material from the stockpile generated by the primary crusher is fed by belt conveyor to a scalper screen. This unit feeds the oversize material to a 1.67-m (5 1/2-ft) secondary crusher. The crushed material and the undersize have a top size of 82 mm (3 to 3 1/2 in.). This aggregate is then fed by belt conveyor to another screen. Undersize passing through the screen falls into a hopper that is unloaded whenever trucks are positioned underneath, or it is belt conveyed to a surge pile. Oversize material is gravity chute fed into two crushers, 0.91-m (3-ft) and 1.22-m (4-ft) shortheads, connected in series. The use of both units is dependent on the size of aggregate being run.

Crushed material, 38 mm to 44 mm (1 1/2 in. to 1 3/4 in.), is transferred from here by belt conveyor to two screens. Undersize stone falls by gravity into two hoppers and is loaded onto trucks periodically. Oversize material is loaded by gravity chute into a crusher, a 1.22-m (4-ft) shorthead, from which the crushed material is conveyor fed back to the conveyor originally

TABLE C-1. PRODUCTION OF CRUSHED STONE - PLANT A

UNIT OPERATION	U	X	Y	Z	TIME	- CHI	Q	UNITS	S
QUARRYING	17.0	615.0	0.0	30.0	45.0	169.0	1.602E0	(G/SEC)	C
QUARRYING	17.0	791.0	0.0	0.0	45.0	135.0	1.595E0	(G/SEC)	C
PRMRY CRUSHER + UNLO	17.0	100.0	0.0	0.0	12.0	648.0	1.808E¯1	(G/SEC)	C
SCNDRY CRUSHER + SCR	8.0	123.0	0.0	0.0	4.0	554.0	1.057E¯1	(G/SEC)	C
SCNDRY CRUSHER + SCR	8.0	123.0	0.0	0.0	8.0	221.0	4.218E¯2	(G/SEC)	C
SCNDRY CRUSHER + SCR	8.0	123.0	0.0	0.0	4.0	280.0	5.344E¯2	(G/SEC)	C
FINES CRUSHER + SCRE	8.0	123.0	0.0	0.0	4.0	114.0	2.176E¯2	(G/SEC)	C
CONVEYING	2.0	110.0	0.0	20.0	4.0	40.0	1.709E¯2	(G/SEC)	C
CONVEYING	2.0	110.0	0.0	20.0	4.0	614.0	2.624E¯1	(G/SEC)	C
UNLOADING TRUCK	8.0	210.0	0.0	0.0	4.0	10.0	5.021E¯3	(G/SEC)	C
UNLOADING TRUCK	8.0	70.0	0.0	0.0	4.0	80.0	5.511E¯3	(G/SEC)	C
UNLOADING TRUCK	8.0	70.0	0.0	0.0	4.0	204.0	1.405E¯2	(G/SEC)	C
UNLOADING TRUCK	8 0	210.0	0.0	0.0	4.0	4.0	2.008E¯3	(G/SEC)	C
LOADING TRUCK	8.0	123.0	0.0	0.0	4.0	74.0	3.390E0	(G)	C
LOADING TRUCK	17.0	40.0	0.0	0.0	8.0	28.0	1.490E¯3	(G/SEC)	C

U = mean wind speed, mph

X, Y, Z = dispersion coordinates (Figure B-1)

Q = emission rate in units shown

S' = stability class

chi = χ = concentration at X, Y, Z

Time = sampling time, min

feeding the screens. All undersize material not guided into the hopper is transferred by belt conveyor to a surge pile. The aggregate top size at this point is 32 mm (1 1/4 in.). Material from the surge pile is conveyed by belt conveyor in a tunnel to a screen, then separated into four sizes: 32 mm, 19 mm, 13 mm or 5 mm (1 1/4 in., 3/4 in., 1/2 in., or 3/16 in.). Any oversize stone is fed by gravity to a gyradisc. This crushed material is then belt conveyed onto the belt originally feeding the screens for sizing. Undersize material is gravity loaded into a hopper.

Trucks then pull under the hopper for loading, then transfer the material on unpaved roads to the appropriate stockpiles. All trucks traveling from the load-out stations, and customer trucks that have been weighed, travel on unpaved roads to the stockpile areas. Empty trucks drive onto the stockpile and are filled by a front-end loader. The front-end loader travels on unpaved roads throughout the storage area either loading trucks or smoothing out the tops of stockpiles. Loaded customer trucks and trucks to be loaded leave the stockpile area and travel to their respective destinations on unpaved roads. Tank trucks spray water on the ground continuously to suppress dust formation.

The plant operates for about 6 hr/day, 5 days/wk. The processing rate through the primary crusher is about 645 metric tons/hr. The remaining crushers operate for about 9.5-hr/day at 2 days/wk.

The sampling data and results from the computer (in accordance with input of Figure B-4) are given in Table C-2.

2. EMISSION FACTORS

The emission factors for respirable and total particulate emissions were summarized earlier in Table 3 (Section IV). The emission factors were derived using the results of sampling, as:

$$\text{Emission factor} = (\text{Emission rate}) \div (\text{Production rate})$$

a. Blasting

The amount of rock blasted was 19,970 metric tons (21,963 tons). At average emission doses of 180 g of respirable particulates and 1,070 g of total particulates, the emission factors for respirable and total particulates are 0.0088 and 0.0522 g/metric ton, respectively.

b. Drilling

The emission factor for drilling was determined by using the sampling data from crushed granite operations, a separate study under contract 68-02-1874. Four readings of ground level concentration were obtained at a wind speed of 0.9 meter/second under D atmospheric stability conditions, 27 meters from the

TABLE C-2. PRODUCTION OF CRUSHED STONE - PLANT B

UNIT OPERATION	U	X	Y	Z	TIME	CHI	Q	UNITS	S'
BLASTING	8.0	204.0	0.0	0.0	16.0	393.0	1.798E2	(G)	C
BLASTING	8.0	204.0	0.0	0.0	55.0	678.0	1.066E3	(G)	C
SCNDRY CRUSHER + SCR	5.3	70.0	0.0	10.0	4.0	742.0	1.242E¯1	(G/SEC)	B
SCNDRY CRUSHER + SCR	5.3	70.0	0.0	10.0	12.0	418.0	6.995E¯2	(G/SEC)	B
SCNDRY CRUSHER + SCR	5.3	70.0	0.0	10.0	4.0	590.0	9.874E¯2	(G/SEC)	B
SCNDRY CRUSHER + SCR	5.3	70.0	0.0	10.0	12.0	198.0	3.314E¯2	(G/SEC)	B
TERTIARY CRUSHER + S	5.3	123.0	0.0	0.0	4.0	50.0	1.191E¯2	(G/SEC)	B
TERTIARY CRUSHER + S	5.3	123.0	0.0	0.0	4.0	272.0	6.479E¯2	(G/SEC)	B
FINES CRUSHER + SCRE	5.3	130.0	0.0	0.0	4.0	27.0	7.115E¯3	(G/SEC)	B
FINES CRUSHER + SCRE	5.3	130.0	0.0	0.0	4.0	10.0	2.635E¯3	(G/SEC)	B
UNLOADING TRUCK	5.3	123.0	0.0	0.0	4.0	140.0	8.003E0	(G)	B
UNLOADING TRUCK	5.3	70.0	0.0	0.0	4.0	10.0	2.043E¯1	(G)	B
UNLOADING TRUCK	5.3	90.0	0.0	0.0	4.0	25.0	8.081E¯1	(G)	B
UNLOADING TRUCK	5.3	100.0	0.0	0.0	8.0	28.0	2.194E0	(G)	B
UNLOADING TRUCK	5.3	90.0	0.0	0.0	4.0	20.0	6.465E¯1	(G)	B
UNLOADING TRUCK	5.3	70.0	0.0	0.0	4.0	22.0	4.495E¯1	(G)	B
UNLOADING TRUCK	5.3	90.0	0.0	0.0	4.0	672.0	2.172E1	(G)	B
UNLOADING TRUCK	5.3	100.0	0.0	0.0	8.0	27.0	2.116E0	(G)	B
UNLOADING TRUCK	5.3	90.0	0.0	0.0	4.0	72.0	2.327E0	(G)	B
LOADING TRUCK	5.3	90.0	0.0	0.0	4.0	222.0	7.176E0	(G)	B
LOADING TRUCK	5.3	90.0	0.0	0.0	4.0	80.0	2.586E0	(G)	B

U = mean wind speed, mph

X, Y, Z = dispersion coordinates (Figure B-1)

Q = emission rate in units shown

S' = stability class

chi = χ = concnetration at X, Y, Z

Time = sampling time, min

source. The concentration, 6.7 meters from the centerline was 70, 130, and 130 micrograms per cubic meter and 560 micrograms per cubic meter on the plume centerline. The calculated emission rates were 11.59, 21.52, 21.52 and 67.28 milligrams per second, respectively. The average emission rate from wet drilling in such operations is 0.015 g/s. At an average rate of 2 hr/hole, 30 holes/blast, and 19,970 metric tons/blast, the emission factor for total particulates is 0.158 g/metric ton. It is assumed (based on sampling at granite operations) that 10% of the particulate is respirable, yielding an emission factor of 0.0158 g/metric ton.

c. Quarrying

The average emission rate for total particulates is 1.60 g/s. At a production rate of 533 metric tons/hr (586 tons/hr), the emission factor is 10.5 g/metric ton. It is assumed (based on sampling at crushed granite operations) that 10% of the particulate is respirable, resulting in an emission factor of 1.05 g/metric ton.

d. Primary Crushing and Unloading

The emission rate for respirable particulates is 0.178 g/s. The crushing and unloading operations occurred for 12 minutes, thus yielding a dose of 128 g of respirable particulates. Three 32-metric ton (35-ton) trucks were unloaded into the crusher during this 12-minute interval. The emission factor is thus 1.34 g/metric ton.

e. Secondary Crushing and Screening

At Plants A and B two average respirable emission rates of 0.048 g/s and 0.066 g/s at production rates of 533 metric tons/hr and 631 metric tons/hr (694 tons/hr), respectively, resulted in a mean emission factor of 0.342 g/metric ton. The 95% confidence limits are ±0.324 g/metric ton. Two total emission rates for Plants A and B, of 0.1057 g/s and 0.097 g/s, respectively, produced a mean emission factor of 0.62 g/metric ton ± 0.997 g/metric ton at the 95% confidence level.

f. Tertiary Crushing and Screening

At Plant B's production rate of 631 metric tons/hr, the respirable particulate emission rate is 0.0119 g/s. The emission factor is thus 0.0665 g/metric ton. The total particulate emission rate is 0.0648 g/s (at Plant B) with an emission factor of 0.362 g/metric ton.

g. Fines Crushing and Screening

Two total emission rates, 0.0218 g/s and 0.00712 g/s, were calculated at Plants A and B, respectively. At the production rates of 533 metric tons/hr and 631 metric tons/hr, the mean emission factor for these two plants is 0.0918 g/metric ton ± 0.662 g/metric ton at the 95% confidence level. The respirable emission rate from Plant B is 0.00263 g/s, resulting in a factor of 0.0147 g/metric ton.

h. Conveying

At Plant A emission rates of 0.0171 g/s and 0.262 g/s for respirable and total particulates, respectively, yield emission factor of 0.113 g/metric ton and 1.73 g/metric ton.

i. Unloading of Trucks

At Plant B the 2.37-g respirable emission dose, based on the unloading of a 32 metric ton truck, gives a factor of 0.0746 g/metric ton. At Plant A the respirable emission rate of 0.005 g/s at the production rate of 533 metric tons/hr produces a factor of 0.033 g/metric ton. The mean emission factor is 0.0538 ± 0.264 g/metric ton at the 95% confidence level. For total particulates, at Plant B the dosage of 6.65 g for a 32 metric ton truck yields a factor of 0.209 g/metric ton. At Plant A the mean emission rate of 0.00669 g/s at 533 metric tons/hr results in a factor of 0.0442 g/metric ton. The mean factor is 0.127 ± 1.05 g/metric ton (at the 95% confidence level).

j. Loading of Trucks

The mean dose rate for total particulates from both plants is 5.28 g. Loading a 32 metric ton truck gives a factor of 0.166 g/metric ton. The respirable particulate rates of 0.022 g/s and 0.00149 g/s yield a factor of 0.0453 g/metric ton.

k. Wet Unpaved Road Traffic

The diffusion equation used for unpaved road emissions is (33):

$$Q_L = D_t \sqrt{\frac{\pi}{2}}\, \sigma_z u. \qquad \text{(C-1)}$$

(C-1)

where D_t = dosage, $g \cdot s/m^3$

π = 3.14

u = wind speed, m/s

σ_z = vertical dispersion, m

Q_L = line dose rate, g/m

At a respirable particulate concentration of 20 $\mu g/m^3$, once a 240-second period, at a distance of 36.6 m and a wind speed of 1.25 m/s, two vehicles emit particulates at the rate of 0.00864 g/vehicle-meter. At a total particulate concentration of 114 $\mu g/m^3$, the emission rate is 0.0492 g/vehicle-meter. The respirable emission factor (E_R) is calculated for the average unpaved road distance of 750 meters traveled by the average of 17 vehicles per hour as follows:

$$E_R = \frac{\left(\frac{8.64 \times 10^{-3}\ g}{veh.\text{-}m}\right)\left(\frac{17\ veh.}{hr}\right) 750\ m}{533\ \text{metric tons/hr}} \qquad \text{(C-2)}$$

converted to:

$$E_R = 0.202\ \text{g/metric ton}$$

The total emission factor is calculated in the same manner to be 1.15 g/metric ton.

Using the data given in Appendix A.1, the emission factors for NO_x and CO were determined. At Plant A there were 20,426 metric tons of rock blasted using 6.08 metric tons of ANFO. Every kilogram of ANFO used creates 0.00625 cubic meters of NO_x. The emission factor was thus calculated and converted to 2.85 g/metric ton. For carbon monoxide, there was 0.00873 m^3 of CO

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(33) Gifford, F. A., Jr. Chapter 3 - An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Alade, D. A. (ed.). Publication No. TID-24190, U.S. Atomic Energy Commission Technical Information Center, Oak Ridge, Tennessee, July 1968. p. 445.

produced per kilogram of ANFO used, and the emission factor was 1.68 g/metric ton.

3. ANALYTICAL RESULTS

Results of the elemental, free silica, and fiber analyses are presented in Tables C-3, C-4, and C-5, respectively. The only hazardous constituent of the dust is the free silica (Table C-3). The mean free silica content is 1.57% (Table C-4). The emission factor for respirable and total particulates containing free silica is then computed from these data. However, if greater than 1% free silica is detected, the entire emissions are considered free silica - thus the emission factors are equivalent to the particulate emissions factors.

The fiber analysis of Table C-5 measured all fibers for preliminary analysis purposes. No attempt was made to determine which fibers were asbestos. At 62 meters downwind from the blasting operation, the fiber concentration was 5.4 fibers/ml (or 5.4×10^6 fibers/m^3).

4. COMPUTATION OF ERROR IN EMISSION RATE

The value of emission rate, Q, is determined in the field by application of Gaussian dispersion equations to the concentrations obtained with the high-volume and GCA samplers. These emission values have a standard deviation which is a function of the standard deviation of the variables. The emission rate is calculated using Turner's (23) estimates of atmospheric dispersion from ambient measurement of χ. In high-volume samplers, there is an error due to inconsistent airflow rates and there are errors in time measurements and weighing which are part of the emission error.

The values of atmospheric stability as reflected by the standard deviations (σ) in the horizontal and vertical planes are valid for a sampling time of 10 minutes. The vertical deviation is expected (23) to be correct within a factor of two for all stabilities out to a few hundred meters, and neutral to moderately unstable conditions in the lower 1,000 meters of the atmosphere with a marked inversion above for distances out to 10 kilometers or more. Since all GCA sampling was performed within a few hundred meters of the unit operations, these conditions were met. For the quarrying activity (high-volume samplers) the distance was greater; however, the emission rates calculated were within 0.6% of their mean calculated value.

The estimate of horizontal dispersion, σ_y, will be less uncertain than that of σ_z. The emission determined (for the three cases cited) will therefore be within a factor of three for variations of σ_y, σ_z and u (23). Hence, the overall standard deviation (σ) in determining emission rate can be estimated as follows:

TABLE C-3. ELEMENTAL ANALYSIS OF EMISSIONS FROM CRUSHED STONE QUARRIES[a]

(percent)

Element	Plant A, Quarry	Plant B		
		Blasting	Primary crusher	Plant activity
Silicon	4.8 to 14.3	3.0 to 9.1	11.8 to 35.3	6.3 to 18.9
Calcium	2.4 to 4.7	3.0 to 9.1	5.9 to 11.8	3.2 to 6.3
Sodium	4.8 to 14.3	3.0 to 9.1	5.9 to 11.8	6.3 to 18.9
Iron	2.4 to 4.8	1.5 to 3.0	5.9 to 11.8	3.2 to 16.3
Aluminum	2.4 to 4.8	1.5 to 3.0	5.9 to 11.8	3.2 to 16.3
Magnesium	0.33	0.9	2.4	1.9
Titanium	0.24	0.21	0.7	0.5
Tin	0.19	0.012	0.024	0.12
Chromium	0.14	0.012	0.47	0.01
Lead	0.1	0.012	0.51	0.19
Vanadium	0.1	0.06	0.035	0.025
Manganese	0.04	0.024	0.094	0.06
Copper	0.04	0.03	0.12	0.13
Nickel	<0.005	<0.006	0.005	0.006
Zirconium		<0.006	0.005	0.025
Silver		<0.003	0.007	0.025
Zinc			0.47	0.252
Molybdenum			0.24	0.044
Boron			0.12	

[a]Cation elemental analysis is shown as percent by weight of total material; oxides and carbonates predominate the anion form.

Note: Blanks indicate that element concentration is below the detection limit of the instrument.

TABLE C-4. FREE SILICA ANALYSIS FROM CRUSHED STONE QUARRIES

Sample	Free silica, %
Plant A	
Background	1.44
Quarrying	2.31
Blasting	2.43
Primary crusher	0.78
Mean	1.74
Plant B	
Plant activity	1.4
Mean of Plants A and B	1.57
Standard deviation	0.24
±95% Confidence interval	2.16

TABLE C-5. FIBER ANALYSIS FROM CRUSHED STONE QUARRIES

A fiber is a particle greater than 5 μm in length with an L/D_f of 3 or greater.

- Sampling results:

  Field area = 0.005 mm^2
  Count = 100 fields
  Average count per field (sample of blasting emission from Plant B) = 0.16

- Fiber concentration at 62 meters (204 ft) from the source = 5.4 fibers/ml
- Emission factor for fibers = $128 \times 10^6 \frac{\text{fibers}}{\text{metric ton}}$
- Maximum source severity (at 410 m) = 0.018
- Affected population due to emissions from a representative crushed stone plant = zero

$$\sigma = \sqrt{(\sigma_1)^2 + (\sigma_2)^2} \qquad \text{(C-3)}$$

where σ_1 = estimated population standard deviation from sampling for χ

σ_2 = additional standard deviation in calculation of Q from χ

A factor of three is defined as follows:

$$\frac{X' + \sigma_2}{X' - \sigma_2} = 3 \qquad \text{(C-4)}$$

where X' = any average value calculated or measured.

From Equation C-4, a factor of three in the calculation of Q implies:

$$\sigma_2 = 0.5\ X' \qquad \text{(C-5)}$$

Therefore, all values of emission rate computed in this document are correct within the "factor" as defined in the above discussion.