Note: This is a reference cited in *AP 42, Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources.* AP42 is located on the EPA web site at www.epa.gov/ttn/chief/ap42/

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AP42 Section:	13.2.2
Reference:	2
Title:	Fugitive Dust Emissions From Trucks On Unpaved Roads R. J. Dyck and J. J. Stuke Environmental Science And Technology, 10(10):1046-1048, October 1976.

Table IV. Wettability and Oil Removal Results

Packing material	Hexane retention time, s, t_H	Water retention time, s, t_W
Anthracite coal	8	32
Ottawa sand	8.5	7.5
Polypropylene	31	11
Polypropylene	...	...
XAD-2	167	17

[a] The relative concentration data, with one exception, were ob for Ottawa sand, for which absolute concentrations were obtainec

#3 PRIMARY TEST REPOI
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RETURN TO AP-42

UNPAVED ROADS
AP-42
Section 11.2.1
Reference Number
2

in the emulsion is also an important factor, though it was maintained approximately constant in the present study.

As a result of this work, evidence exists that oil-wet packing materials provide better coalescing media than water-wet materials for the treatment of oil-in-water emulsions.

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Fugitive Dust Emissions from Trucks on Unpaved Roads

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■ An expression for estimating the fugitive dust emissions from trucks operating on unpaved construction site haul roads is given. The expression suggests a linear relationship between vehicle speed, vehicle weight, and silt content of the road.

Previous studies have shown that many activities commonly practiced on construction sites significantly degrade the air quality. A consistently cited construction practice that adversely affects the air quality is haul road traffic on unpaved surfaces (*1*). All previous studies that developed vehicle-unpaved road emission factors have examined automobile traffic on unpaved secondary roads (*2, 3*).

This study, however, investigates fugitive dust emissions from construction site haul roads. Thus, heavier vehicles similar to those used on a construction site are employed. Truck movement on access roads to construction sites differ from secondary road automobile traffic in the following ways. Trucks generally travel at slower speeds because of the proximity of the construction site, transport much greater weights, contact the road differently, and possess different aerodynamic wake characteristics. In addition, the intrinsic road characteristics of temporary haul roads may vary from those typical of secondary roads.

The objective of this study was to characterize the source particulate emission strength of an unpaved haul road as a function of various vehicle, road, and meteorological parameters. This study focuses on such controlling parameters as vehicle speed, vehicle weight, road surface moisture content, road surface particle size distribution, and road surface soil type.

Theory

To calculate the source emission strength of the measured atmospheric concentrations, the following infinite line source equation was used (*3, 4*):

$$C(x, y, 0, H) = \frac{2\,q}{\sin\phi\sqrt{2\,\pi}\,\sigma_z U} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad (1)$$

For purposes of describing dust emissions by vehicle transport over the "infinite line source", the source strength calculation must also take into account the rate of road use. Rearranging the above equation and taking into account the rate of road use give:

$$e = \frac{C \sin\phi\,\sqrt{2\,\pi}\,\sigma_z\,Ut}{2\,N} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad (2)$$

In an attempt to relate the source strength to the road, vehicle, and meteorological parameters, a multiple regression analysis was performed. The variables considered in the analysis included the vehicle speed, V; the vehicle weight, W; the percentage of silt in the road surface, S; surface moisture, M; the road type, R; and the wind speed, U.

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Experimental Procedure

The criteria used to select the site included: A road should be selected which could be isolated from other traffic during the test period, the test road should be typical of roads used for temporary construction hauling activities, the area adjacent to the test area should be open to preserve the applicability of the dispersion formula and allow noncontroversial placement of the instrumentation, the roads should be straight to preserve the "infinite line" source approximation, and there should be several roads in the test area having different orientations to accommodate daily wind direction variations.

A site in Champaign, Ill., satisfied all the criteria. Existing unpaved roads at the site were used for heavy vehicle access to a construction area. Laboratory analysis confirmed the normative nature of the surface soil when compared to surface soils that were typical of other temporary haul roads in most northern regions of the country. Since the dispersion equation calls for a wind-road angle ranging from 45° to 135°, the road orientations permitted testing for all wind directions but 6° out of a possible 360°.

A 4½-ton flat-bed truck with a four-wheel drive was the lone test vehicle driven. The vehicle parameters, velocity, and weight represented by low, medium, and high values were defined to form a 3 by 3 vehicle matrix.

Sand bags were utilized to vary the weight of the truck. The weight distribution used for test purposes were: low, 8580 ± 100 lb; medium, 12610 ± 100 lb; and high, 16530 ± 100 lb. Weighing after each test revealed no measurable weight loss due to factors such as gasoline usage. Low weight corresponded to an almost empty truck, while high weight approximated the safe carrying capacity of the truck. The indicated weights also represented convenient arrangements of sand bags.

Preliminary test runs with the heavy weight over the test roads marked a maximum safe traveling speed of 25 mph. Trucks transporting materials to construction sites across temporary access roads appear to seldom exceed 30 mph. Therefore, 10, 17½, and 25 mph represent low, medium, and high vehicle velocities. The various speed-weight combinations were run in random order to insure that variables unaccounted for in this study become part of the overall experimental error.

Four standard high-volume air samplers measured downwind concentrations at distances ranging from 50 to 250 ft downwind, while a fifth sampler measured background concentrations. In the event of a nonusable concentration measurement at a particular measuring station, three other downwind measurements prevented an otherwise invalidation of an entire test. By averaging the emission factors calculated from data at four separate stations, the reliability of the results of each test was enhanced.

The wind speed and direction and other meteorological variables were measured using standard meteorological instruments. The effective height of dust emission which resulted from the trailing wake of the truck was estimated visually to be 1 m. A road surface sample was taken during each test and analyzed for moisture content, percent of silt particles, and type of soil. Each test period was approximately 1 h in duration. All tests were conducted under dry road conditions. Dry road conditions were defined as being those which prevailed after two days of dry weather. Precedent for testing under dry road conditions was set by previous studies (*2*).

Prior to the initiation of each experimental test, the probable wind direction for the test period was estimated, thereby specifying the corresponding test road. For these estimates, local weather forecasters were consulted. Because of the cumbersome nature of the monitoring equipment and the prolonged time required to move and position the equipment, the reliability of wind direction predictions prevailed in determining the time required to perform each test. These estimates proved highly reliable on some days and highly unreliable on others. For the most part, lower wind speeds shifted directions more frequently than higher wind speeds. Sunset and sunrise, however, invariably produced extremely stable winds coupled with low wind speeds. On some days, winds shifted so frequently so as to prevent tests until the approaching sunset. Some tests were abruptly halted when winds shifted radically in midtest. At other times, winds remained remarkably consistent throughout the day.

As noted above, the meteorological variables such as instantaneous wind speed and direction were recorded during each run. In addition, the number of truck passes along the test tract and the duration of the test were recorded. The effective height of the plume over the road bed was estimated visually and was approximately 1 m for all tests. By analyzing the instantaneous variation of the wind direction, the standard duration, σ_θ, about the mean wind direction was calculated. This allowed the stability class to be determined using the Pasquill's stability criteria. By knowing the location of each sampling station relative to the road and the stability class of the atmosphere, the value of σ_z was determined using standard charts (*4*). Finally, the measured concentration was determined gravimetrically at each of the sampling stations. Equation 2 was then used to calculate the emission factor, e, for each station. The emission factors for all four stations were then averaged to give an overall emission factor.

The variable R accounts for varying road types. Two of the roads used for testing had nonplastic surface soils both described as silty sands and sand–silt mixtures (USCS classification of SM). A third road had inorganic clays of low to medium plasticity, silty clays, and lean clasy (USCS classification of CL). The model arbitrarily assigned a value of 1 to SM road types and 0.0 to CL road types. This was done to test the importance of soil plasticity in the prediction of dust emissions. Additional studies are underway to more accurately assess the effect of road type on emissions.

Discussion of Results

A stepwise regression analysis revealed that two groups of variables were statistically significant at the 95% confidence level. The resulting expression is:

$$e = 5.286 - 3.599\,R + 0.00271\,VWS \quad 10 \text{ mph} \le V \le 25 \text{ mph} \qquad (3)$$

where V is expressed in mph, W in thousands of pounds, S as a percentage, and e in lb/vehicle-mile. R is dimensionless. For example, the predicted emissions for an 8-ton truck traveling on a nonplastic soil surface ($R = 1$) with a 10% silt content at a speed of 15 mph would be

$$e = 5.286 - 3.599\,(1) + 0.00271\,(15)\,(8)\,(10)$$

$$e = 4.939 \text{ lb/vehicle-mile}$$

The multiple correlation coefficient associated with the relationship given above is 0.7974.

The model emission equation shown above applies only to the particulate matter captured on the high-volume air samplers. A study by the Midwest Research Institute showed that for typical meterological conditions, and for a particle density of 2.5 g/cm^3, the standard high-volume air sampler has a 30-mm effective cutoff diameter (*2*). Particles with larger diameters generally settle out of the air within 25 ft of the road. Although these particles may constitute a nuisance in areas immediately adjacent to unpaved roads, they do not contribute to the ambient dust levels at locations far removed from the road.

Note that Equation 1 neglects any loss of particles due to sedimentation between the road and the samplers. Except in

the immediate vicinity of the road, this is a valid assumption for this study. Evidence to support this claim can be found by examining the variation of the emission factor calculated using only the data for a particular measuring station. If there were considerable fallout as the dust plume progressed downwind, a systematic decrease in the calculated emission factor would be observed for each station. The experimental results indicate that there was no systematic variation of the emission factors. Thus, for this study, it can be concluded that fallout was not a significant variable. Similarly, no systematic variation in the emission factor was observed for those runs in which the wind was not perpendicular with the road.

Variations in the moisture content of the soil proved to be statistically insignificant at the 95% confidence level. Since testing included only dry days (as defined earlier), possible dust emission vs. moisture content threshold effects may have been eclipsed.

As noted earlier, this study uniquely varies from previous studies of automobile traffic on secondary roads. The magnitude of the dust emissions from automobiles and trucks is expected to be different. There are several possible reasons for this. First, road contact and/or wheel parameters would be expected to influence the result. For example, MRI (*2*) reported a linear relationship between the number of wheels on a vehicle and the road dust emission levels. Second, the size and shape of the vehicle may affect the aerodynamic wake in the immediate vicinity of the vehicle. The primary factors affecting the characteristics of the wake are the aerodynamic conditions underneath the vehicle and the tip vortices which are formed on the rear end corners of the vehicle. In this study the sand bags were placed in the aerodynamic "bubble" generated behind the cab of the truck. The placement of the bags in this zone would not materially affect the characteristic of the wake. Because of these factors, the comparison of results for automobiles and trucks is difficult. Although the magnitude of the results should differ, the functional form of the analytical expression for automobiles and trucks should be similar.

The MRI study (*2*) for automobiles reported the following expression for the dust emissions:

$$e = 0.81\,SV \quad 30 \text{ mph} \leq V \leq 40 \text{ mph} \tag{4}$$

whereas PEDCO (*3*) reported

$$e = 0.27\,(1.068)^{V} \quad 15 \text{ mph} \leq V \leq 40 \text{ mph} \tag{5}$$

In the above equations, V is expressed in mph and S as a percentage.

When we compare the functional form of these two results with Equation 3, the results of this study and MRI are similar.

The trucks used in this study had six wheels, whereas automobiles have four wheels. If it is assumed that a pure wheel proportionality exists for the fugitive dust emissions from various types of vehicles (as suggested by the results of the MRI study), then a comparison can be made between the results of the MRI study and the present study. This is accomplished by multiplying the MRI and PEDCO results by a factor of 1.5. Table I gives the results of such a comparison for a vehicle speed of 27.5 mph. This vehicle is slightly out of range of both the MRI and the present study but is adequate for comparison of results. The emission values reported in Table I were calculated using Equations *3–5*. Examination of the table suggests that the results presented here and those of MRI are comparable. Further, the data suggest that the vehicle weight influences road emissions. In addition, this study suggests that road type is a factor. Unfortunately, the precise definition of its role will have to wait until a current ongoing project is completed.

Table I. Comparison of Predicted Fugitive Dust Emissions from Automobiles and Trucks for Vehicle Speed of 27.5 mph [a]

S	R	W	e_{PEDCO}	e_{MRI}	$e_{PEDCO} \times 1.5$ [b]	$e_{MRI} \times 1.5$ [b]	e
5	1	8.58	1.65	3.71	2.47	5.57	4.88
5	1	16.53	1.65	3.71	2.47	5.57	7.84
5	0	8.58	1.65	3.71	2.47	5.57	8.48
5	0	12.61	1.65	3.71	2.47	5.57	9.97
5	0	16.53	1.65	3.71	2.47	5.57	11.43
10	1	8.58	1.65	7.43	2.47	11.14	8.96
10	1	12.61	1.65	7.43	2.47	11.14	11.09
10	1	16.53	1.65	7.43	2.47	11.14	12.32
10	0	8.58	1.65	7.43	2.47	11.14	12.55
10	0	12.61	1.65	7.43	2.47	11.14	14.68
10	0	16.53	1.65	7.43	2.47	11.14	15.93
20	1	8.58	1.65	14.85	2.47	22.28	14.47
20	1	12.61	1.65	14.85	2.47	22.28	20.48
20	1	16.53	1.65	14.85	2.47	22.28	26.33
20	0	8.58	1.65	14.85	2.47	22.28	18.07
20	0	12.61	1.65	14.85	2.47	22.28	24.08
20	0	16.53	1.65	14.85	2.47	22.28	29.94

[a] S, percentage of silt particles on road surface; R, dimensionless; W, truck weight in thousands of pounds; e, road emissions in lb/vehicles-mile. [b] Correction for number of wheels or present study's truck.

Conclusion

An expression for estimating the fugitive dust emissions from trucks operating on unpaved temporary construction site haul roads has been reported. The expression suggests a linear relationship between vehicle speed, vehicle weight, silt content of the roadbed, and type of road. If a pure wheel proportionality is assumed to exist between the fugitive dust emissions for vehicles, the results of the present study are comparable to those reported by MRI.

Nomenclature

e = emission factor
C = particulate matter concentration
q = line source strength
ϕ = angle between the wind direction and a line source
σ_z = standard deviation in the verticle direction of the plume concentration
U = wind speed
t = duration of experiment
H = effective height of dust emission
N = number of truck passes
V = vehicle speed
W = vehicle weight
S = road surface percentage of silt particles
M = road surface moisture
R = road type

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SIR: In the July 1975 issue of *Environmental Science and Technology*, there appeared a note by Devine and Partington (*1*) reporting carryover of sulfate in the direct distillation of fluoride samples of 95–1300 mg/l. as SO_4^{2-}. In synthetic samples containing known amounts of fluoride and sulfate, fluoride values as much as four times the true concentration were observed.

If such sulfate carryover were typical of results obtained by analysts in general, serious doubt would be cast on fluoride analyses of direct distilled samples, since a concentration of 200 mg/l. sulfate in the distillate will cause a positive error of 0.1 mg/l. fluoride at a true concentration of 1.0 mg/l. if the SPADNS method is used for analysis. The alizarin visual method is less sensitive to sulfate, 300 mg/l. being required to produce an error of 0.1 mg/l. fluoride.

To investigate the magnitude of sulfate carryover, a series of distillations was conducted with sulfuric acid–distilled water mixtures, and the distillates were analyzed for sulfate. To investigate the effect of sulfate carryover on apparent fluoride concentration, synthetic samples containing 0–1 mg/l. fluoride with 0–50 mg/l. sulfate were analyzed for apparent fluoride concentration.

Procedure

For distillation the all-glass apparatus shown in "Standard Methods for the Examination of Water and Wastewater", 13th ed., figure 18, p 221, was used. The upper parts of the apparatus were shielded from the flame by supporting the flask on an 8-in. asbestos board with a 2¾-in. perforation in the center (similar to Scientific Products P-1850-13). In some distillations the asbestos board was omitted or replaced by a wire screen with an asbestos center. Four hundred ml of distilled water and 200 ml of concentrated sulfuric acid were placed in the flask, glass beads were added, and the contents thoroughly mixed and distilled in a fume hood until a thermometer with tip immersed in the acid reached 180 °C. After cooling to below 120 °C, 300 ml of distilled water was added, and the distillation repeated as before. Sulfate was determined on the entire distillate or on 25-ml fractions by the turbidimetric method.

Results

Table I shows sulfate concentrations in the distillate fractions from sulfuric acid–distilled water mixtures with use of an asbestos board shield and with and without use of hood ventilation.

Table II shows the absence of effect of organic matter on carryover of sulfate into the distillate and effect of substitution or removal of the asbestos shield.

Table III shows the effect of known sulfate concentrations below 50 mg/l. on apparent fluoride concentrations at known concentrations of 0–1 mg/l.

As shown by Bellack (*2*), carryover of sulfate occurs only during the final stages of the distillation, beginning after distillation of 150–175 ml. Although the concentration of sulfate in the final 25 ml of distillate exceeds 250 mg/l., dilution reduces the concentration in the total 300 ml of distillate to well below 50 mg/l. Dilution of the hot gases from the burner by use of the hood fan had little effect on the total sulfate concentration in the distillate, although sulfate first appeared at a slightly higher temperature.

Reduction of sulfate to sulfite by addition of starch to the distillation mixture apparently did not occur. Sulfate carryover in this run was somewhat lower than in previous tests.

Omission of the asbestos shield or its replacement by a wire gauze with asbestos center resulted in an approximately tenfold increase in sulfate carryover. Although omission of the asbestos shield resulted in more rapid distillation and considerable foaming, there was no more spray carryover with a distillation rate of 200 drops/min than at a slower distillation rate and without foaming.

Use of an asbestos shield is recommended in "Standard Methods" (*3*), but is not further described or illustrated. Bellack (*2*) does not mention use of a shield. The distillation head in the apparatus shown in the above procedures is more remote from the flame than that of the one-piece distilling flask used in this study and may not require as extensive shielding for low sulfate carryover. The perforated asbestos board as described above has proved to be satisfactory in the reduction of sulfate carryover to acceptable levels.

Table I. Sulfate Carryover in Fluoride Distillation Under Different Conditions

	Conditions of distillation	
Fraction, ml	Asbestos shield used with hood fan	Asbestos shield used without hood fan
0–25	<0.8	...
25–50	<0.8	...
50–75	<0.8	...
75–100	<0.8	...
100–125	<0.8	...
125–150	<0.8	...
150–175	<0.8	1.6
175–200	4.8	5.6
200–225	4.8	8.8
225–250	<2.0	20.8
250–275	46.0	84.8
275–300	263.0	328.0
Av (0–300)	26.6	37.4

Table II. Effect of Shielding on Sulfate Carryover in Fluoride Distillation

Condition of distillation	Sulfate in distillate, mg/l.
Asbestos shield used Hood fan on	26.6
Asbestos shield used Hood fan off	37.4
Asbestos shield used Hood fan off 200 mg/l. soluble starch in acid mixture	23.6
Wire gauze shield used Hood fan off	320
No shield Hood fan off	360
No shield Hood fan off Distillation rate 200 drops/min	270

Table III. Effect of Sulfate on Observed Fluoride Concentration in Synthetic Samples (mg/l.)

Sulfate added	Fluoride added	Fluoride found	Sulfate added	Fluoride added	Fluoride found
0	0.00	0.00	0	0.60	0.62
10	0.00	0.00	10	0.60	0.62
20	0.00	0.00	20	0.60	0.60
30	0.00	0.00	30	0.60	0.63
40	0.00	0.00	40	0.60	0.62
50	0.00	0.15	50	0.60	0.63
0	0.20	0.20	0	0.80	0.80
10	0.20	0.20	10	0.80	0.80
20	0.20	0.23	20	0.80	0.85
30	0.20	0.23	30	0.80	0.80
40	0.20	0.27	40	0.80	0.80
50	0.20	0.27	50	0.80	0.85
0	0.40	0.40	0	1.00	1.02
10	0.40	0.38	10	1.00	1.03
20	0.40	0.40	20	1.00	1.02
30	0.40	0.40	30	1.00	1.02
40	0.40	0.44	40	1.00	1.03
50	0.40	0.44	50	1.00	1.02

As shown in Table III, sulfate levels in the distillate below 40 mg/l. have no effect on apparent fluoride levels between 0 and 1 mg/l. At 50 mg/l. sulfate, there was an apparent concentration of 0.15 mg/l. fluoride in the blank, and at 40 and 50 mg/l. sulfate, there was an increase of 0.07 mg/l. apparent fluoride in standards containing 0.2 mg/l. fluoride. At higher fluoride concentrations, there were minor random variations in apparent fluoride concentrations.

The experiments reported here do not account for the extreme sulfate concentrations in the distillates as reported by Devine and Partington. Even under the most unfavorable conditions, the maximum sulfate concentration observed was 360 mg/l.

The samples used by Devine and Partington, with the exception of one each of sewage and septic tank water, would be expected to contain exclusively inorganic materials removable by distillation. It is interesting that the highest sulfate carryover in the series was obtained with a distilled water sample. For sewage and other wastes containing volatile organics, a preliminary precipitation of fluoride with magnesium oxide followed by dilution and distillation is recommended.

Conclusions

Sulfate carryover can be readily held below 40 mg/l. in the fluoride direct distillation, provided an asbestos shield is used to deflect hot gases from the upper parts of the distilling apparatus.

With the asbestos shield, sulfate carryover begins when 175 ml has been distilled, provided hood ventilation is used, and when 150 ml has been distilled without hood ventilation.

As observed by Bellack (2), sulfate is diluted to concentrations within acceptable limits in the entire 300-ml distillate.

Substitution of the asbestos shield by a wire gauze or omission of any shield resulted in sulfate concentrations in the distillate of 320 and 360 mg/l. It was necessary to reduce the flame size under these conditions to avoid spray carryover.

Sulfate effect on apparent fluoride concentrations is significant only at fluoride concentrations of 0.0–0.2 mg/l. and at sulfate concentrations of 40 mg/l. or more.

Reduction of sulfuric acid to sulfur dioxide by oxidizable organic matter and subsequent oxidation to sulfate in the distillate does not occur under the distillation conditions.

Abandonment of the distillation and SPADNS method in favor of the electrode method would be premature since there would be no independent method of confirming electrode method results.

Our experience with the fluoride electrode is limited. Fluoride concentrations as determined by the electrode method in our laboratory are equal to or lower than those determined by the SPADNS method. The discrepancy increases with increasing fluoride concentration.

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SIR: We are in general agreement with Mr. Zehnpfennig's findings. The purpose of our paper ("Interference of Sulfate Ion on SPADNS Colorimetric Determination of Fluoride in Wastewaters") was to point out that the Bellack distillation and SPADNS colorimetric method was a poor method of choice because of the variable sulfate contamination problem. It is obvious that Mr. Zehnpfennig went to great lengths and introduced tedious techniques to hold the sulfate concentration to an acceptable level. We feel that a "standard" method should not require such tedious care to obtain valid results.

The method of distillation suggested by Mr. Zehnpfenning would not be acceptable in our laboratory. We have eliminated the use of all exposed asbestos due to OSHA regulations. The distillation equipment used in our laboratory is similar to that pictured on page 196 of Part 23 of the 1972 "Annual Book of ASTM Standards". Presently, we have four such sets of equipment under one hooded bench area.

To obtain data to compare with Mr. Zehnpfennig's, we *distilled four aliquots of deionized water* (one in each of our four units). The results are listed in Table I. Note that we obtained as high as 365 mg/l. of sulfate in a composite distillate.

We feel that our article and Mr. Zehnpfennig's article both demonstrate that a potential problem exists in the distillation–SPADNS combination. Either the distillation step should be better defined, or as we suggested a method free of sulfate interference used (the ion selective electrode method).

Table I. Sulfate Carryover in Fluoride Distillation

Distillate fraction, ml	mg/l. SO_4			
	Unit 1	Unit 2	Unit 3	Unit 4
25–50	<5	<5	<5	<5
50–75	<5	<5	<5	<5
75–100	<5	<5	<5	<5
100–125	<5	<5	<5	<5
125–150	<5	<5	<5	<5
150–175	<5	<5	<5	<5
175–200	25	<5	<5	10
200–225	170	15	5	15
225–250	500	130	35	45
250–275	1000	500	330	450
275–300	2650	1750	2000	3250
Average	365	220	200	320

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