REPORT NO. AR-642

CHARACTERISTICS OF THE DUST ENVIRONMENT IN THE VICINITY OF MILITARY ACTIVITIES

FINAL REPORT

by

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George W. Knebel

January 1968

U. S. Army Mobility Equipment Research and Development Center
Fort Belvoir, Virginia 22060

Contract No. DA-44-009-AMC-1009(T)
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CHARACTERISTICS OF THE DUST ENVIRONMENT IN THE VICINITY OF MILITARY ACTIVITIES

Final Report
Contract No. DA-44-009-AMC-1009(T)
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to
U.S. Army Mobility Equipment
Research and Development Center
Power Equipment Division, SMEFB-EP
Fort Belvoir, Virginia 22060

Submitted by
Department of Automotive Research
Southwest Research Institute
8500 Culebra Road, San Antonio, Texas 78206

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FOREWORD

This report is one of a series of reports prepared under Department of the Army Project No. 1A025001A622. A number of environmental investigations have been performed under this project most of which were under the administrative direction of Mr. P.W. Espenschade, now retired, and formerly assigned to Headquarters, U.S. Army Materiel Command. This contract was placed under the able direction of Mr. D.D. Faehn, Power Equipment Division, U.S. Army Mobility Equipment Research and Development Center without whose assistance little could have been accomplished.

The authors also wish to express their appreciation for the courtesies extended to them by the commanding officers of the U.S. Army installations where the sampling activities were conducted. Special acknowledgement is due the following persons and their staff who aided this program by supplying supporting personnel, vehicles, and equipment.

Fort Hood
  Lt. Col. Raymond E. Bell

Fort Bliss
  Capt. John V. Blondell

White Sands Missile Range
  Messrs. Ferdig, Alarcon, and Mueller

Fort Huachuca
  Mr. John Sliter

Yuma Proving Ground
  Messrs. Floyd Watts and W.C. Christopher

ABSTRACT

Measurement of the dust environment was conducted at five military installations in the southwestern United States. The purpose of these measurements was to establish the important characteristics of the dust clouds which would be experienced by stationary equipment in the vicinity of various types of military activity. The main emphasis was placed on vehicular created dust clouds although some data were gathered from several other dust producing situations.

The results showed a very wide variation indicating that many factors can and do influence the dust environment. The data were sufficient to support several broad generalizations regarding some effects on cloud duration, visibility and concentration.

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I. INTRODUCTION

The characteristics of dust environment are of interest because of the potential of this condition to cause rapid failure of many types of Army equipment. In particular the advent of more and faster vehicles, and the increased reliance on helicopters and ground launched missiles have served to intensify or increase the dust problem. In other words, the Army is making more dust today than it did 20 years ago. To further compound the problem there is increased usage of the gas turbine. It is probable that the gas turbine requires no better air filtration than does the reciprocating engine. However it does present difficult air filtration problems, due to the low allowable air intake restriction and large quantity of intake air.

For these reasons the dust environment existing around various military activities is necessarily an important area of study. It is the purpose of this report to discuss the characteristics of this environment and to establish quantitatively some of the factors influencing these characteristics.

There has been in the past and probably always shall be in the future, many unanswered questions concerning the dust environment. Typical of these questions are:

1. The concentration to which Army equipment will be exposed.

2. The duration and frequency of these concentrations.

3. The degradation potential of the dust.

4. When and where the dust is likely to be encountered.

In order to answer these questions it is necessary to recognize several basic facts. It must be understood and accepted that a great number of factors influence the generation of a dust cloud. This leads to two basic approaches which might might be taken. The first of these is to quote broad ranges of data which will take into account almost all conditions and the second is to specify a number of precise conditions with corresponding precise dust environment characteristics.

Quantitative expressions of a dust concentration are useless unless specific information is included which describes the conditions under which measurements are made. Basic supporting data is required which identify the dust producer, the nature of the terrain, and where and how the resultant dust cloud was sampled. Translating the above statement into greater detail, it is possible to prepare a partial listing of the major variables which affect the physical characteristics of the dust cloud. Such a list is shown below.

Major Factors Affecting the Dust Environment

A. Dust Producer

1. Type
2. Size
3. Traction media
4. Speed

B. Terrain

1. Particle size
2. Surface compaction
3. Mineralogical characteristics

C. Climatic Conditions

1. Wind velocity
2. Wind direction
3. Humidity
4. Air density

D. Sampling Technique

1. Geometric relation between dust source and sampler

   a. Distance from dust producer
   b. Height above terrain
   c. Location with respect to wind direction

2. Sampling time

3. Sampler characteristics

Further discussion regarding each of the above factors will be included in the text and it is not necessary to enlarge on them at this time. It is of more concern to understand that each of these factors is both highly variable and very influential in determining the amount of dust that will be captured by a dust sampler at any given time. As stated earlier one may either define the dust conditions along with all of the restricting variables or cite a range of variables along with a corresponding range of dust environment characteristics. It goes without saying that broad ranges of conditions produce corresponding broad ranges of dust data. This process can be continued until the data reaches the point of complete uselessness. As an example, the dust concentration can be stated to fall somewhere between .000001 to 1 gram per cubic foot depending upon the military activity, the distance the sampler is located from the activity and the terrain; one can be completely confident that such a statement is accurate but its utilitarian value is highly speculative.

If an ideal solution is to be reached concerning a definition of the dust environment it is similarly necessary that ideal solutions be resolved regarding the typical conditions associated with the dust environment. Even if almost all conditions are constant, seemingly minor variations of the operation of the dust producer can cause large fluctuations in the dust concentration. To illustrate this point, Table I is the measured concentrations produced by a 58, 000 pound crawler tractor bulldozing very dry earth into a pit. Each concentration measurement was taken over a 30 second time period and all nine samples were made within one hour under conditions which were identical.

TABLE I
Variation in Dust Samples Produced by a Bulldozer

Distance from Dust Producer Feet	Visibility (At Sample Point) Feet	Concentration gms/cu. ft.
120	0-50	.00063
120	0-50	.00026
120	0-50	.00027
120	0-50	.00175
120	0-50	.00146
120	0	.00519
120	0	.00135
120	0-20	.00153
120	0	.00162

The data in Table I has a variation of about 20:1 in the concentration. The obvious question is what is the true or typical concentration to be expected? There is no simple answer to this question. It can be stated that it averages .0016 gms/ft^3 or that it ranges from .0003 to .005 gms/ft^3. Either of these answers is technically correct but they each present a different impression of the dust cloud. It is therefore necessary to make some judgment regarding the use of such data and whether it is more appropriate to use the range of individual concentrations or whether an average figure is sufficient.

If it is assumed that the 20:1 range of the measured values shown in Table I is typical of almost constant measurement conditions relative to a single type of operation, it may be seen that the inclusion of a few more normally occurring variables such as soil moisture or wind velocity can easily increase the dust concentration range a great deal further. Consequently, dust concentration data must always be viewed as being very sensitive to the conditions which prevail at the time of measurement; apparent contradictions are often explained by this situation and should at least be considered from this standpoint.

There are additional characteristics of the dust environment other than concentration and these, too, are subject to a variation equal to that of concentration. Such characteristics as the duration and frequency of occurrence do not necessarily lend themselves to theoretical treatment and must be expressed largely in terms of ranges and averages rather than in absolute values.

Thus, the dust environment description is a complex of many factors that are not simply described. Even though a great deal of data and numbers are included in this report, this does not negate the need for additional or further work which might be accomplished in the future. Basically, each new situation encountered and measured will produce data that may or may not fall within previously published figures. Such things are inevitable. It is more important to recognize and accept this as a fact. Further discussion of this point shall be included later.

This report attempts to present a few of the ramifications of the dust environment surrounding some typical military activities. For the most part, emphasis is placed upon that dust environment which is experienced by stationary equipment as opposed to moving equipment such as might be experienced by vehicles or airborne equipment such as helicopters. Original data plus data from references have been used in an effort to present a more complete discussion of the dust condition.

II. PARTICLE SIZE AND AGGLOMERATION

A. General

Particle size and agglomeration are the two prime characteristics of a soil which establish the potential dustiness of the locale. It is very often difficult to separate these two factors because the state of agglomeration, of course, affects the apparent particle size.

The particle size of the dust cloud is also of interest. It determines the floatation of the cloud, it has an important role in establishing the type of air filter to be used for protection and in general affects the amount of dust that will reach the engine since most air filters become less effective as the particle size decreases.[1] As an example of the effect of particle size on air cleaners an inertial separator type was found to have an efficiency of about 94 per cent with 0 to 200 micron coarse dust; the efficiency dropped to 84 per cent when 0 to 80 micron fine dust was fed to the cleaner under the same conditions.[2]

B. Meaning of Particle Size

Since dust particles are irregular in shape, any expression of their size must necessarily be explained. Particles larger than 74 microns are universally measured by sieves or screens. This is a convenient and quick procedure requiring a minimum of equipment and technique. Particles which pass through a 74 micron sieve are often referred to as being sub-sieve sized although they may be further separated by sieves having smaller openings using special techniques.

There are a number of ways to express the size of sub-sieve particles and Table II lists some of them. It may be seen from an examination of Table II that a considerable variety of measurements exists which can create rather large apparent discrepancies between the data depending upon measurement technique. An illustration of this is a series of tests in which

TABLE II
Definitions of Particle Diameter[5]

Parameter	Description
Diameter	Measured diameter of a sphere or a particle in one direction.
Area Diameter (Projected)	Diameter of a circle having the same area as the projected area of the particle.
Area-length Diameter	Diameter obtained by dividing projected area by measured diameter.
Volume-surface Diameter	Diameter obtained by dividing volume of particle by surface area.
Area Diameter	Diameter of a sphere having the same cross-sectional area as the particle.
Volume (Mass) Diameter	Diameter of a sphere having the same density and volume or mass as the particle.
Stokes Diameter	Diameter of a sphere having the same density and free falling speed as the particle in gas.
Perimeter Diameter	Diameter of a circle having the same perimeter as the particle.

particle size was measured by a photoextinction technique and a sedimentation method. Differences in the two sets of data were as much as 15 per cent by weight for certain sizes and types of particles.[3] Other investigators have stated that the ratio between the area diameter (most often measured by microscope) and the sieve aperture through which the particle will pass is 1:4.[4] Comparisons between particle sizes based on Stoke's diameter and by sieving have resulted in correction factors ranging from 1.2 to 0.9.[4]

The primary point of this discussion is that in the literature particle size has been measured by a variety of techniques in the sub-sieve size range. Unless these techniques are described along with the data, comparisons between data sources may not be completely valid.

C. Particle Size of Air Floated Dust

Inasmuch as this particular study is concerned with the dust experienced by stationary equipment all sampling was done by placing a sampler in a fixed location in the vicinity of some type of activity such as a passing vehicle. Under these conditions enough dust cannot be collected in the sampler to make a particle size determination. There have been a number of size determinations made of the dust size distribution created by vehicles. Some of this data is shown in Table III which was taken from Reference 6. Table III includes the size distribution of coarse test dust which supposedly is also representative of airborne dust.

The increased use of helicopters has created considerable interest regarding the size of the particles in the dust cloud created while they hover close to the ground. Unlike vehicles, the extremely high air velocities generated by a helicopter are capable of lifting very large particles which can be well above 200 microns. Therefore, the dust size distribution experienced by a helicopter and equipment in its vicinity is largely a function of the size of particles which are on the terrain surface. For instance, if there are quantities of loose 200 and 300 micron particles on the surface, these will be present in the helicopter dust cloud. Discussions with personnel returning from Cam Ranh Bay in Viet-Nam, a sandy area containing few if any particles below 74 microns,[7] indicate that particles of several hundred microns are freely blown about by helicopters causing erosion damage to the helicopters as well as nearby equipment.

TABLE III

Size Distribution of Dust Collected at Air Inlet of Army Tanks

Size Microns	M4A1 Tank Engine Air	M48 Tank Engine Air	M48 Tank Crew Air	Coarse Test* Dust
0-10	12.5	42.4	60.2	24
10-20	28.0	13.7	15.7	14
20-40	43.0	16.8	12.2	23
Above 40	11.5	27.1	10.9	39

One of the primary objectives of measuring the particle size of air floated dust is to establish the required air cleaner characteristics. It was reported by one source that with the types of air cleaners he was evaluating, poor correlation was found between air cleaner efficiency and the particle size of several natural and manufactured dusts.[8] As an alternative it was suggested and experimentally shown that particle area per unit weight of dust correlated better with air cleaner efficiency than did particle diameter.

D. Particle Size of Terrain Soil

The particle size of the parent soil should logically be a good indicator of the potential "dustiness" of an area. There are no good criteria to establish how much of the parent soil should be

Coarse dust for testing air cleaners per Society of Automotive Engineers "Air Cleaner Test Code", also known as AC Coarse dust composed of dust sized particles to produce heavy or moder·.e dust. It is known that particles above 150 microns have a rapid settling rate (about 100 centimeters per second) and therefore will fall out quite quickly. However, for the purposes of this study an arbitrary diameter of 74 microns was chosen for correlation with the amount of dust produced by various sources. There are several reasons for choosing this diameter. Table III indicates that the majority of the airborne dust is less than 40 microns while other sources state that vehicle dust plumes are almost all less than 74 microns.[9] Another important reason is that it is an easily measured diameter which can be found in most of the literature and last, fine test dust also has a maximum particle size about this size and the performance of many air cleaners can be related to this sized dust.

Soil samples were taken at 17 locations in this study. The percentages of these soils below 74 microns are shown in Table IV. It is interesting to note the wide range of particle percentage below 74 microns at any location. This is primarily caused by terrain surface modification rather than differences in soil type. Some of these surfaces were graded compacted roads while others were unimproved trails. Correlation of the percentage of particles below 74 microns with dust concentration is difficult because of the many extraneous variables. Table V presents selected data indicating this influence. All data in this table reflect the amount of dust raised by 1/4 and 3/4 ton vehicles traveling between 25 and 35 miles per hour with the sampler located 25 to 40 feet from the vehicle path. Table V indicates a general tendency for the concentration to increase as the percentage of smaller particles increases. In fact, the concentration varies almost directly with the percentage of 74 micron particles. This data, however, are too meager to completely validate this conclusion. In reviewing the complete data, it appears that at least moderate dust clouds might be raised by the passage of light vehicles traveling about 30 miles per hour when the percentage of 74 micron particles is

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*Fine dust for testing air cleaners per Society of Automotive Enginee.s "Air Cleaner Test Code", also known as AC Fine dust

TABLE IV
Percentage of Soil Particles Below 74 Microns

Location	Particle Percentage	Surface Type
Ft. Hood, Texas	16.6	Trail
"	25.2	Trail
"	38.5	Trail
Ft. Bliss, Texas	5.7	Road
"	7.6	Road
"	8.1	Road
"	24.4	Field
White Sands Missile Range, N.M.	8.3	Launch Complex
Ft. Huachuca, Arizona	1.4	Road
"	4.9	Road
"	5.6	Road
"	8.6	Road
"	9.4	Trail
Yuma Proving Ground, Arizona	9.1	Road
"	10.1	Trail
"	13.3	Trail
"	21.0	Road

TABLE V
Influence of Amount of "Dust Sized" Particles
In Soil on Dust Concentration

% of Soil Less Than 74 Microns	Depth of Loose Material on Surface, in.	Concentration mg/ft^3
7.6	1/4-1	.10
8.1	1/4-1	.13
8.1	1/4-1	.23
9.1	<1/4	1.4
9.1	<1/4	1.9
9.1	<1/4	3.1
21.0	<1/4	2.4
21.0	<1/4	3.2

around nine per cent or higher. Concentrations of one to three milligrams per cubic foot were recorded under these circumstances at one location. The heaviest concentrations recorded were from a soil containing one to four inches of loose powder that was 13.3 per cent less than 74 microns. During the passage of a heavy wheeled vehicle at 20 to 35 miles per hour the concentrations ranged from 11 to 39 milligrams at a distance of 25 feet which, by any standard, is a very heavy dust concentration.

Substantiation of this data is possible by reviewing particle size measurements of other soils known to produce heavy dust concentrations. Two such soils are the test courses at Yuma Proving Ground and Aberdeen Proving Ground. Data from these two sites is shown in Table VI. In general the percentage of particles less than 74 microns corresponds to subjective observations of the concentrations produced on the courses at Aberdeen and Yuma. The Churchville course at the time of measurement was rather uniformly dusty and those locations at Yuma Proving Ground showing low percentages of 74 micron particles (2.9, 5.9, 6.3) were not as dusty as the other sample points.

E. Particle Size of Other Soils

Using the general guidelines established, i.e., around nine per cent less than 74 microns for moderate dust conditions and about 14 per cent or higher for heavy dust conditions, it is possible to crudely evaluate the potential dust condition in additional localities. Table VII contains a listing of soil particle sizes gathered from a number of areas.

Table VII indicates that there are many localities outside of the desert areas that might experience moderate to heavy dust conditions. While Table VII does not prove the point, it is a strong probability that appreciable quantities of dust can be produced almost anywhere in the world providing the soil moisture content is low and the surface agglomeration of the particles is not excessive. It might also be pointed out that with the exception of the continuously wet tropics, maritime environments, and the high arctic, all areas of the world experience sufficient dry periods during some part of the year to produce dust.

TABLE VI
Soil Particle Size of Vehicle Test Courses[10]

Location	% Less Than 74 Microns
Yuma Proving Ground	
Muggins Mesa	45.0
Vapor Lock Gulch	14.4
" " "	2.9
Tank Hill Course, High Hills	25.1
" " " , Low Hills	19.9
Tank Cross Country, Wash	5.9
" " " , Foot Hills	6.3
" " " , Plain	12.4
Truck Cross Country, Light Volcanic	30.6
" " " , Dark Volcanic	28.2
Aberdeen Proving Ground	
Churchville Sample 1	7.6
" " 2	14.8
" " 3	23.6
" " 4	30.4
" " 5	21.4
" " 6	29.7
" " 7	18.1
" " 8	10.4

TABLE VII

Dust Producing Capabilities of Various Localities[8, 11]

Location	% Less Than 74 Microns	Dust Capability
Amarillo, Texas	12	Moderate
Salina, Kansas	19	Heavy
Spokane, Washington	40	Heavy
Cairo, Egypt	0.7	Light
Tunisia	9	Moderate
Hickam Field, Hawaii, Volcanic	9	Moderate
Hickam Field, Hawaii, Coral	3	Light
Nichols Field, Manila	6	Light
Biae Island	22	Heavy
Canton Island	2	Light
Lae, New Guinea	2	Light
Finschaven, New Guinea	30	Heavy
Kwajalein	2	Light
Samarkand Highway, U.S.S.R.	50	Heavy
Highway Near Moscow	100*	Heavy
Country Road Near Moscow	100*	Heavy
Plowed Soil Near Moscow	100*	Heavy

*Maximum particle size stated to be less than 80 microns

The military forces have painfully learned that the tropical areas such as Viet-Nam have sufficient dry periods to produce dust. Even though this area has sufficient moisture and very fine grained laterite soils that produce highly agglomerated surfaces, it will break down under heavy traffic when dry and produce a dusty environment.[7] While it is open to conjecture as to whether traffic either breaks the soil particles or merely deagglomerates them, it can be shown that the end effect is an increase of the smaller particles. For instance it was found that with the exception of almost pure quartz, the clays, loams, limestone, and other fine grained soils can undergo an increase in the 0 to 74 micron range of four to 14 per cent after 250 passes of a light weight vehicle.[9] Increases of this magnitude can easily change a soil from a light to heavy dust producer. Further evidence of deagglomeration by surface activity can be found in Table VIII. Almost every soil surface sample has a smaller particle size than the sub-soil. This table also supports a previous statement as it indicates a number of additional locations having an abundance of dust sized particles. Finally, there are also data indicating that military operations increase the frequency of dust storms in arid areas or create a dusty environment. Clements[12] quotes sources indicating that in western Egypt before and after World War II only three or four dust storms occurred per year but during the war years, 20 to 51 storms per year were observed. This increase in dust storms was directly attributed to military activities and was probably caused by the ensuing destruction of vegetation and slight surface crust which exists on most undisturbed surfaces.

The surface moisture, of course, must be low to produce dust. Surface moisture during the current study was measured and found to range from 1.8 down to 0.2 per cent. This amount and variation of moisture was too small to determine any moisture influences. No literature was found discussing moisture influences on dust conditions but, again, weather records and other sources indicate that low moisture content of soil surfaces can be expected at some time in the majority of world areas. As an example, soil temperatures greater than 140°F are found in the tropics which is ample to promote sufficient surface drying to create dust.

TABLE VIII
Dust Content of Additional U.S. Soils

Location	Soil Mass Median Microns	% Less Than 74 Microns
Perryman Test Course, Aberdeen Proving Ground, Md.		
Topsoil	330	17.4
Subsoil	326	8.2
Dugway Proving Ground, Utah		
Topsoil	254	12.3
3" Subsoil	326	8.6
Kenvil, New Jersey		
Topsoil	480	24.0
Subsoil	105	42.0
Redstone Arsenal, Alabama		
Topsoil	290	17.0
Subsoil	685	4.0
White Sands Missile Range, N.M.		
2" Subsoil	220	3.0
6" Subsoil	228	5.0
San Antonio, Texas		
Black Gumbo, Topsoil	840	2.7
Black Gumbo, 3" Subsoil	840	1.4
Clay Topsoil	238	17.6
Clay 3" Subsoil	665	14.0
Sandy Loam Topsoil	122	17.7
Sandy Loam 3" Subsoil	157	7.1
Delta River, Alaska		
River Bottom Silt	32	83.6
River Bottom Surface Soil	460	2.3
River Bottom 3" Subsurface	340	1.2

III. VISIBILITY

Of course, more dust concentrations have been measured by the visibility reaction of an observer than by any other method. However, it was found that consistent correlation between visibility and concentration is apparently difficult to achieve. This is caused by a number of phenomena, the foremost being the size of the dust particles. Figure I illustrates the response of a photoelectric cell to a constant light source in the presence of different sizes and types of dust. The two AC dusts, coarse and fine, are nearly identical in every respect except size. The fine dust has a mass median size of about 7 microns while the coarse has a mass median size of 30 microns. It may be seen that the amount of light received by the photoelectric cell is much less for the smaller sized dust particles than for the larger particles at any given concentration. This is primarily because the smaller particles have a larger cross-sectional area per unit weight than the larger particles.

On the other hand, the AC coarse dust reduced the light transmission slightly more than the 105 micron silica flour. The mass median size of the silica flour is between 20 and 25 microns which is somewhat lower than the AC coarse. It is intuitively expected that the silica flour (crushed quartz) would produce a higher meter response or less light transmission because it is a smaller dust. However, light scattering, particle shape, and light absorption are all factors which affect the transmission[13] and in this case, combine to increase the relative light transmission through the silica flour as compared to the AC dust. To cite a more dramatic example of the effect of particle size on visibility, very large quartz particles (500 to 800 microns) were introduced at concentrations up to 100 mg/ft^3 and produced essentially no response from the photoelectric cell indicating almost 100% transmission of light.

Almost no data were found that could be used for comparison with the results of this report. Although there are a number of sources quoting measurements of general atmospheric visibility

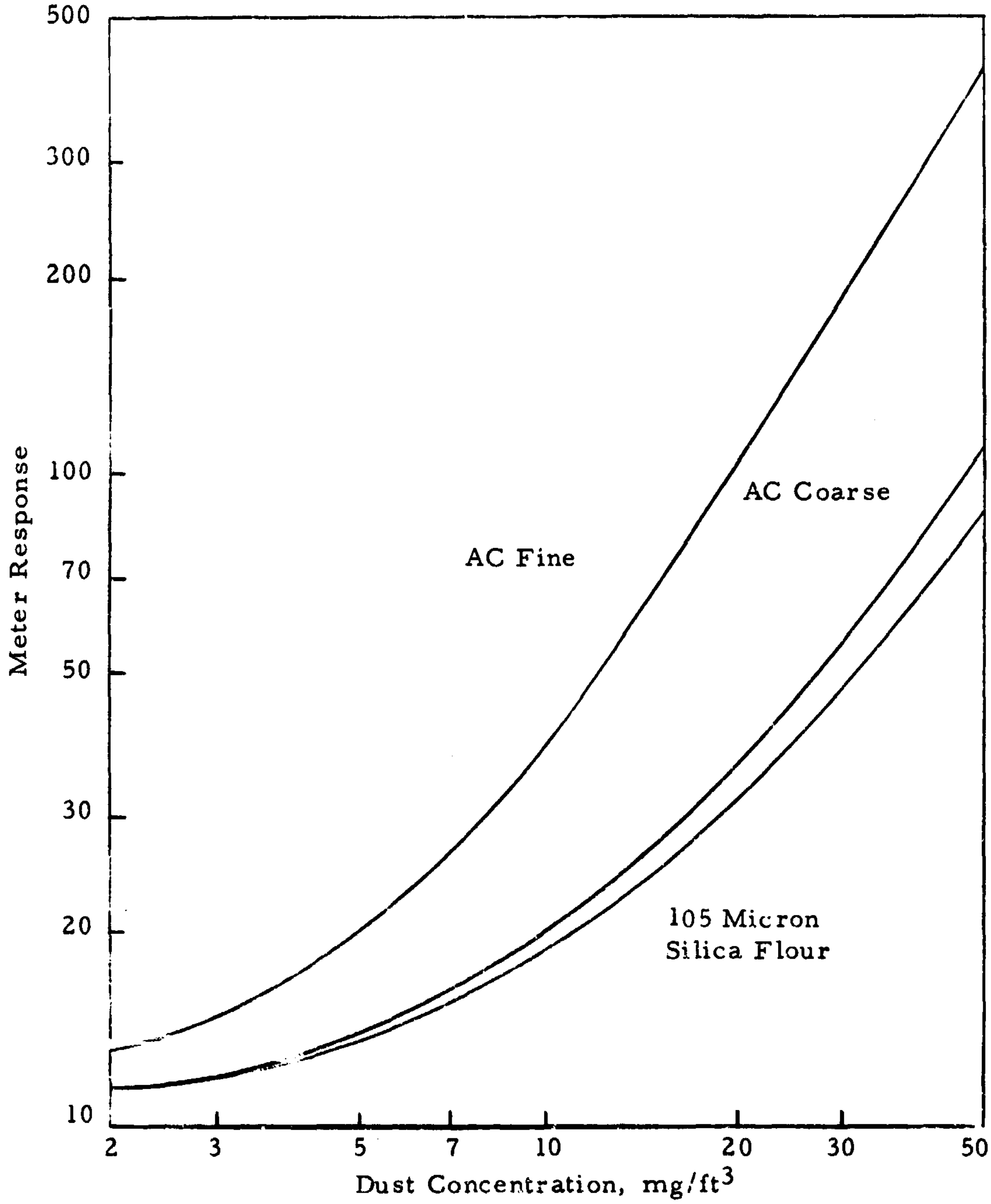

FIGURE I. Response of Photoelectric Cell To Dust Concentration as correlated with concentrations of fog, smoke, dust, and other types of pollutants[5, 13, 14] these data are not applicable to the current study. The primary reasons for this are that the particles are generally smaller than those raised by vehicles thereby producing higher visibility restriction per unit concentration and the characteristics of the pollutant particles bear little resemblance to vehicle raised dust particles.

There is also considerable information regarding visibility in dust storms but these data are not accompanied by concentration measurements. Pavia[15] did measure dust storm concentrations in Australia by flying aircraft through them and reported the following characteristics for a storm having a 1000 foot visibility.

Height Above Ground, Ft.	Concentration, mg/ft^3
500	0.057
1000	0.493
2000	0.197
3000	0.051
4000	0.018

The only other source of comparison with the data in this report is a general statement that a concentration of 25 mg/ft^3 will produce zero visibility.[16]

The data in Table IX represent the reaction of an observer standing at the sampler. Since the density of a dust cloud is not constant, some of the visibility measurements are reported as a range such as 0 to 50 feet. This can be interpreted to mean that at some point during the passage of the cloud the visibility reached 0 but that 50 feet is probably a better average figure. With the exception of four measurements all data were taken under bright sunshine conditions. No specific observation targets were set out; normal objects were used such as vehicles, personnel, and miscellaneous items of equipment.

TABLE IX
Concentration vs Visibility and Percent of Soil
Less Than 74 Microns

Concentration mg/ft^3	Visibility ft.	Percent of Surface Soil less than 74 microns
0.003	No Restriction (NR)	7.6
0.003	NR	5.7
0.015	NR	7.6
0.022	NR	1.4
0.023	NR	5.7
0.029	NR	7.6
0.038	NR	1.4
0.050	NR	1.4
0.069	NR	4.9
0.087	NR	7.6
0.090	NR	24.4
0.110	NR	7.6
0.132	NR	8.1
0.166	NR	8.6
0.182	NR	8.6
0.183	NR	8.6
0.190	NR	9.1
0.206	NR	8.6
0.231	50	8.1
0.235	50	8.1

Table IX Cont.

Concentration mg/ft^3	Visibility ft.	Percent of Surface Soil less than 74 microns
0.253	500	25.2
0.258	0-50	24.4
0.268	0-50	24.4
0.310	NR	9.1
0.325	50	9.1
	NR	8.1
0.363	NR	8.6
0.316	NR	24.4
0.372	NR	24.4
0.400	100	21.0
0.469	50	5.7
0.470	NR	21.0
0.630	200	21.0
0.633	0-50	24.4
0.680	NR	9.1
0.706	200	5.6
0.753	NR	9.1
0.756	200	5.6
0.800	50	10.1
0.870	10	8.3
0.870	50	21.0
0.900	NR	4.9
1.00	500	21.0
1.24	300	16.6

Table IX Cont.

Concentration mg/ft^3	Visibility ft.	Percent of Surface Soil less than 74 microns
1.30	100	38.5
1.35	0	24.4
1.32	NR	9.4
1.44	NR	9.1
1.46	0-50	24.4
1.53	500	5.6
1.53	0-20	24.4
1.62	0	24.4
1.70	NR	9.1
1.75	0-50	24.4
1.91	NR	9.1
2.41	10	8.3
2.43	50	21.0
2.80	NR	9.1
2.97	5	13.3
3.14	NR	9.1
3.15	50	10.1
3.22	50	21.0
3.34	NR	4.9
3.48	3	25.2
3.49	10	10.1
3.61	50	21.0
3.92	50	10.1
4.98	50	10.1
5.19	0	24.4
7.46	NR	9.1
9.80	500	1.4

Table IX Cont.

Concentration mg/ft^3	Visibility ft.	Percent of Surface Soil less than 74 microns
11.68	5	13.3
21.58	0	13.3
34.02	0	13.3
38.37	5	13.3
39.07	5	13.3

In reviewing Table IX, the following generalizations appear to be justified. With a few exceptions, there are either no restrictions or visibility is greater than 500 feet at concentrations less than 0.4 mg/ft^3. Visibility estimates between 100 and 500 feet predominate at concentrations between 0.4 and 1.3 mg/ft^3. Fifty foot visibility is present at concentrations as high as 5 mg/ft^3 while 0 to 5 foot visibility exists at concentrations from 5 up to 40 mg/ft^3. It is interesting to note the extreme variation of observer reaction to the dust cloud. At certain times concentrations as low as 0.3 mg/ft^3 produced visibility as low as 0 to 50 feet and conversely concentrations as high as 8 and 9 mg/ft^3 were reported as producing either no restriction or 500 feet visibility.

It was thought that the finer grained soils, i.e., those with higher percentages of 0-74 micron particles might produce more opaque dust clouds. These data are also shown in Table IX but appear to have no effect on the visibility, i.e., equal concentrations have equal visibility restrictions regardless of the 0 to 74 micron particle percentage. This lends support to a previous statement that the majority of the dust cloud is composed of 0 to 74 micron particles in which case the relative visibility would be unaffected by 0 to 74 micron particle soil content at the same dust cloud concentration.

A final check was made on the visibility determinations to ascertain any effects caused by variance of the type of soil. For this purpose, two different materials were chosen for comparison. One of these was from Ft. Hood, Texas. The Ft. Hood samples were essentially all caliche; caliche is identified as a young limestone and is very finely divided and white in color. Compared with the Ft. Hood caliche were dusts from Yuma Proving Ground which are about 40 per cent quartz with the remainder made up of clay, carbonates, and gypsum. Particle sizes of the two dusts are compared in Table X and are equivalent.

Table XI contains the results of this comparison. The data in this table are not conclusive nor is the visibility consistent at either location. Very generally, it might be stated that no great difference was found between the two locations.

TABLE X

Particle Size Distribution in Soil Below 74 Microns
(Ft. Hood and Yuma Proving Ground)

Size, Microns	Yuma	Ft. Hood
0-5	9	9
5-10	15	13
10-20	22	28
20-40	34	41
40-74	18	18

TABLE XI
Visibility Restriction Caused by Ground Dust
(Ft. Hood and Yuma Proving Ground)

Location	Concentration mg/ft^3	Visibility ft.
Ft. Hood	0.2	500
"	1.2	300
"	1.3	100
"	3.5	300
Yuma Proving Ground	0.4	500+
" " "	0.4	100
" " "	0.6	200
" " "	0.8	50
" " "	1.0	500
" " "	3.2	50

IV. DURATION

The primary factors affecting the duration of the dust cloud are wind velocity, distance of sample point from the dust source, and the size of the generated cloud. Like visibility, the duration measurement is governed by the personal reaction of the observer to the dust cloud. The duration time shown in Table XII was taken by starting a stopwatch when the dust reached the sampler and stopping the watch when the cloud density was judged to be insignificant. This table is arranged in the order of increasing wind velocity. The distance has been corrected for wind direction and represents the actual distance which the cloud traveled between vehicle and sampler.

The column in Table XII labeled "Dust Intensity" is a combination of several factors that govern the production of the dust plume. The following criteria were used to judge the dust plume severity.

Light - Light, wheeled vehicle traveling less than 20 mph.

Heavy, wheeled vehicle traveling less than 10 mph.

Less than 1/4-inch of loose surface material.

0-74 micron particle fraction less than 5 per cent of total.

Moderate - Light, wheeled vehicle traveling faster than 20 mph.

Heavy, wheeled vehicle traveling between 10 and 20 mph.

Tracked vehicle traveling less than 10 mph.

TABLE XII
Duration of Dust Cloud Produced by a Single Vehicle

Wind Velocity fpm	Actual Distance feet	Dust Intensity	Duration Seconds
200-400	17	Moderate	8
200-400	11	Moderate	8
200-400	11	Moderate	12
200-400	6	Moderate	25
200-400	6	Moderate	5
200-500	92	Heavy	10
200-500	92	Heavy	10
200-500	92	Heavy	25
200-600	21	Moderate	10
200-600	21	Moderate	15
200-600	21	Moderate	19
200-600	21	Heavy	10
200-600	21	Light	10
300-500	50	Moderate	10
300-500	50	Light	6
300-600	25	Moderate	6
300-600	25	Heavy	11
300-600	25	Heavy	9
300-600	25	Heavy	16
300-600	25	Heavy	16
300-600	25	Heavy	24
500-800	216	Heavy	9
500-800	216	Heavy	8
500-1000	28	Light	11
500-1000	28	Light	4
500-1000	28	Light	6
500-1000	28	Light	6
500-1000	28	Moderate	11
500-1000	28	Moderate	12
500-1000	28	Moderate	15
500-1000	28	Moderate	34

1/4 to 1-inch of loose surface material.

0-74 micron soil fraction between 5 and 9 per cent of total.

Heavy - Heavy wheeled vehicle traveling faster than 20 mph.

Tracked vehicle traveling faster than 10 mph.

1-inch or more of loose surface material.

0-74 micron soil fraction higher than 9 per cent of total.

Considerating the number of variables which can affect duration, the data are reasonably consistent and do not show great sensitivity to distance, wind velocity or dust intensity. Durations ranging from 6 to 25 seconds appear to be possible for about any combination of these factors.

As often happens when taking data in the field, unexplainable figures are sometimes recorded. In this case, the last line in Table XII was a 1/4 ton truck traveling at 40 mph and the duration of the cloud was 35 seconds. The vehicle then passed the sample point at 35 mph and the duration time dropped to 15 seconds.

A number of vehicle convoys were encountered during the program. Even though the duration of the dust cloud is basically a function of nothing more than the time for convoy to pass a given point, convoy operation is common and time duration of the resultant dust cloud is of interest. Table XIII contains these data.

The table is arranged in the order of increasing number of vehicles and increasing speed. The time duration follows this trend also. In addition, this table correlates more consistently with distance than Table XII.

TABLE XIII
Duration of Dust Cloud Produced by Vehicle Convoys

No. of Vehicles	Speed MPH	Distance Feet	Duration Sec
2	10	15	12
2	35	77	32
3	35	18	22
3	40	19	12
5	10	92	70
11	15	14	58
14	20	77	124
18	20	19	124
18	20	19	138
24	15	15	114
24	10	15	177
26	15	27	319
27	10	15	183
27	15	15	167
27	15	27	320

V. CONCENTRATION

A. General

One of the most important aspects of the dust environment is concentration. There are two primary expressions for concentration which are number of particles per unit volume of air and weight of dust per unit volume of air. With the exception of applications such as monitoring of clean room air or some air pollution studies, weight of dust per unit volume of air is the more common term for concentration. From the standpoint of units, almost any may be found in the literature but the rather awkward term of grains per cubic foot seems to predominate in the U.S. and Great Britain while the more logical unit of grams per cubic meter is most often found in the countries using the cgs system. The majority of sampling devices measure the concentration as a weight per unit volume of air and it appears that the engineering application of this data is more useful than count data.

It is possible to convert concentration by count into concentration by weight providing something is known regarding the size and distributional characteristics of the dust. Reference 6 contains a mathematical procedure for making this conversion and arrived at the following formula:

$$C_w = 3.894 \times 10^{-5} (C_n)$$

Where:

C_w = Concentration in grams per cubic foot

C_n = Concentration in millions of particles per cubic foot

In deriving the foregoing equation, it was assumed that the dust distribution followed certain conditions[17] and was similar in size to that found in previous measurements of air floated dirt in Arizona. This allowed the following constraints to be used in the derivation:

1. 50% of the number of particles are equal to or less than 0.75 microns.

2. 90% of the number of particles are equal to or less than 2.5 microns.

3. 90% of the weight of the sample was composed of particles larger than 3 microns.

Thus, the two measurements may be converted from one to the other; however, the conversions do require certain assumptions regarding the distribution and size which may not be valid for all types of dust.

B. Isokinetic Sampling

Measurement of concentration is most often done with a sampler which consists of a vacuum pump that pulls air through a barrier filter. The intake air speed of the sampler may or may not be controllable or constant. It is desirable to obtain a dust sample isokinetically which means that the dust sampler intake velocity is equal to the ambient air velocity. A sample taken in this manner is conceded to be the most accurate because there are minimal centrifugal effects around the entrance of the sampler thus negating alterations of size distribution. However, isokinetic sampling is difficult to accomplish because it (1) requires a sophisticated sampler capable of detecting and matching ambient air speed; (2) the air volume passing through the sampler must be measured by an integrating device which can convert instantaneous air flow to total air flow, and (3) at low ambient air speed, the isokinetic sampler has a correspondingly low air flow thus producing a very small collected sample which tends to increase measurement error.

Another consideration when studying concentration data is that regardless of the sampling technique used, isokinetic or otherwise, air breathing equipment does not experience the same dust distributional pattern as taken in by the sampler. This is simply because the air inlet speed of air breathing equipment does not match the ambient air speed (unless by accident); therefore alteration of the distributional pattern of the dust will result.

Not only will the size distribution of the dust be altered but the concentration will be altered as well. There is little theoretical treatment of isokinetic sampling effects on concentration but a few investigators have made some observations.[13] Some of these data are shown in the following table which has been compiled from several sources. The 17 and 31 micron data are in closer agreement with the preponderance of the other data than the 100 and 10 micron data.

TABLE XIV
Effect of Sampling Speed on Concentration
(After Reference 13)

Particle Size Microns	Particle Density gm/cm^3	Va/Vs	C/C_o
17	1.05	1.5	1.10
17	1.05	0.8	0.95
31	1.3	1.5	1.18
31	1.3	0.8	0.85
100	1.0	1.5	1.99
10	1.0	1.5	1.54
100	1.0	0.5	0.67
10	1.0	0.5	0.82

Va - Ambient Air Speed
Vs - Sampler Inlet Speed
C - Measured Concentration
C_o - True Concentration

It can also be shown that the concentration of the sample is affected by facing the sampler away from the direction of the wind. The following approximate values were reported indicating the effect of the angle between the sampler inlet and the wind direction using diethyl phthalate particles.

TABLE XV
Effect of Angle Between Wind Direction and Sampler Inlet
(After Reference 13)

Angle, °	Mass Median Diameter, Microns*	C/C_o
90	4	0.70
60	4	0.86
30	4	0.91
90	12	0.45
60	12	0.78
30	12	0.89
90	37	0.12
60	37	0.70
30	37	0.85

As may be seen, the ratio of measured to true concentration (C/C_o) is affected much more by the larger diameter particles than the smaller ones. This is entirely logical because the particles possessing the larger inertia or kinetic energy will require stronger forces to make them deviate from their straight line path.

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*The mass median diameter is the mid-point of the size versus weight distribution of a sample of particles.

This data is not directly applicable to natural dust because the majority of natural dusts have a much higher density (greater than 2 g/cm^3) and therefore possess a much higher inertia. It does indicate that for particles having a density of about 1-g/cm^3 the following results may occur:

1. If ambient air speed is 1.5 times sampling speed:

   a. The concentration of 100 micron particles in the captured sample may be doubled over that in the dust cloud.

   b. The concentration of 1 micron particles will be almost unaffected.

2. If ambient air speed is half of the sampling speed:

   a. The concentration of 100 micron particles will be about 70% of that in the natural cloud.

   b. The concentration of 1 micron particles will be almost unaffected.

3. The concentration of the larger particles may be severely reduced by facing the sampler away from the wind. As an example, Table XV indicates a concentration reduction of 88% of a sample having a mass median of 37 microns when the sampler is pointed at 90° to the wind direction and 15% when pointed at 30° away from the wind.

Since the literature indicated these rather severe concentration effects on low density particles caused by sampler orientation, it was decided to attempt experimental verification. The purpose of this experiment was to determine the magnitude of the change in concentration caused by differences in the angle between the sampler inlet and wind direction. This information could be used not only as a correction factor to the data in this report but also as a possible guide for positioning air inlets to reduce dust concentration. A sampler was placed in the field in the presence of dust clouds which appeared to be relatively constant. Table XVI contains the results of this test.

TABLE XVI
Effect of Sampler Orientation

Sampler Orientation	Condition	Concentration mg/ft^3
Vertical	A	0.09
Facing Wind	A	0.3
Vertical	B	1.3
Facing Wind	B	1.4
Down Wind	B	1.6
Vertical	C	0.029
Facing Wind	C	0.015

The information in Table XVI is inconclusive indicating that in one instance vertical sampling resulted in a reduced concentration, in another it had no effect, and in the third situation it increased the concentration. Therefore, it was decided that for practical purposes, the possible deviation caused by differences between sampler inlet direction and wind direction fall within the normal deviation of the concentration.

C. Concentration Measurement Technique

It must be clearly understood that the concentration of dus[illegible]ssing a stationary point is time variant. No instrument is available, which is rugged enough for field use, that will measure instantaneous concentration or concentration versus time. If such data could be obtained, the resulting curve would probably rise quite sharply, level off and then decay slowly.

A dust sampler measures some type of average concentration. The data are very dependent on the reaction of the observer. If the dust cloud is small and lasts only a few seconds, concentration deviations of 50 to 100 per cent can be caused by midjudgement of arrival and dissipation time of the cloud. The average concentration of a dust cloud is probably adequate information for most purposes but the reader should be aware that the concentration data in this report and that of others do not reflect the true picture of the condition.

D. Discussion of Concentration Data

Depending upon nomenclature, there are at least 10 to 20 known factors which have a direct influence on the amount of dust a vehicle will create. There are probably this many more factors which have gone unsuspected. Consequently, the same dust sampling conditions never appear twice. The sampling program was therefore directed at a broad range of conditions in order to present the general situation. No particular attempt was made to sample the severe conditions although some were found; more emphasis was placed on gathering data under usual or normal conditions.

The five locations visited were Ft. Hood, Texas; Ft. Bliss, Texas; White Sands Missile Range, New Mexico; Ft. Huachuca, Arizona; and Yuma Proving Ground, Arizona. Attempts were made to arrive at these sites when something "interesting" was going on. Actual sampling was conducted at several locations at each site which ranged from open unimproved areas to hard compacted roads.

The measurements and observations made during each sample run were as follows:

1. Type of activity (vehicle speed, size, number, etc.)
2. Type of surface
3. Depth of loose material
4. Per cent of 0 to 74 micron particles in loose material.
5. Moisture content of loose material
6. Sky conditions
7. Relative humidity
8. Dry bulb temperature
9. Wind velocity
10. Wind direction

11. Distance of sampler from activity
12. Height of sampler above surface
13. Visibility restriction
14. Dust concentration

Table XVII contains most of the concentration data pertaining to vehicles. It is arranged in the order of increasing speed and vehicle size. In this table the following classifications were used:

Light Wheeled Vehicle - 1/4 to 3/4-ton
Heavy Wheeled Vehicle - 2-1/2-ton and larger
Light Tracked Vehicle - Under 15 tons
Heavy Tracked Vehicle - Over 15 tons
Heavy Surface Dust - 0-74 micron fraction of soil sample exceeds 9% of total and depth of loose material on surface greater than 1/4 in.
Light Surface Dust - 0-74 micron fraction of soil sample is less than 9% and depth of loose material is less than 1/4 inch.

The data are quite variable. Somewhat more weight should probably be given to the multiple vehicle figures which are not indicated as a convoy. These data are the result of multiple passes of the indicated number of vehicles during which time the sampler was turned on and off. In this way, data representing a larger sample was obtained.

During the sampling procedure dust moisture ranged from 1.78 to .22 per cent, ambient temperature from 87 to 104°F, relative humidity from 10 to 57 per cent, and sampler height from 2 to 9 feet. None of these variables had a detectable effect on the data. Wind velocity, duration, and particle size ranges have been previously discussed.

E. Additional Measurements

Several concentration measurements were made which are not shown in Table XVII. The following paragraphs discuss these data.

TABLE XVII
Effect of Vehicle Speed and Distance on Concentration

No.*	Vehicle Velocity	Size**	Dust Concentration gm/ft^3	Distance Feet	Surface*** Dust
			Single Vehicle		
1	5 mph	LW	.0047	28	H
1	10 mph	LW	.001	28	H
1	15 mph	LW	.00063	28	H
1	20 mph	LW	.0004	28	L
1	20 mph	LW	.0007	21	L
1	20 mph	LW	.0009	30	L
1	25 mph	LW	.0009	28	L
1	25 mph	LW	.0028	21	L
1	25 mph	LW	.0031	11	H
1	25 mph	LW	.0050	17	H
1	30 mph	LW	.0008	6	H
1	30 mph	LW	.0032	28	L
1	30 mph	LW	.0033	30	L
1	30 mph	LW	.0035	6	H
1	30 mph	LW	.0039	11	H
1	30 mph	LW	.0075	21	L
1	35 mph	LW	.0024	28	L
1	40 mph	LW	.0017	21	L
1	40 mph	LW	.0036	28	L
1	20 mph	HW	.0384	25	H
1	25 mph	HW	.0297	25	H
1	30 mph	HW	.0340	25	H
1	30 mph	HW	.0391	25	H
1	30 mph	HW	.00032	77	H
1	35 mph	HW	.0117	25	H
1	35 mph	HW	.0216	25	H
1	20 mph	HT	.0012	210	H
1	35 mph	HT	.0012	210	H

Table XVII Cont.

No.*	Vehicle Velocity	Size**	Dust Concentration gm/ft^3	Distance Feet	Surface*** Dust
			Multiple Vehicles		
11C	15 mph	LW	.0013	14	L
18C	20 mph	LW	.000003	77	H
Several	25 mph	LW	.00013	77	H
2	25 mph	LW	.00019	21	H
2	25 mph	LW	.0014	21	H
10	30 mph	LW	.00024	77	H
2	30 mph	LW	.0031	21	L
2	35 mph	LW	.00075	21	L
2	35 mph	LW	.0019	21	L
3C	40 mph	LW	.0015	19	L
10	45 mph	LW	.00023	77	H
27	10 mph	HW	.00018	15	L
2C	10 mph	HW	.00018	15	L
24C	10 mph	HW	.00021	15	L
27C	15 mph	HW	.00017	15	L
24C	15 mph	HW	.00036	15	L
18C	20 mph	HW	.00071	16	L
18C	20 mph	HW	.00076	19	L
2	35 mph	HW	.00047	77	L
3C	35 mph	HW	.0098	18	L
5C	10 mph	LT	.00025	92	H
3	30 mph	HT	.0035	92	H

*No.
No. of Vehicles
(C - Convoy)

**Size
LW - Light Wheeled
HW - Heavy Wheeled
LT - Light Tracked
HT - Heavy Tracked

***Surface Dust
H - Heavy
L - Light

Tank Firing - An M-60 tank was followed through a firing course at Ft. Hood. The sampler was approximately 12 feet above the ground and the distance from the tank probably varied from 40 to 90 feet. Terrain dust was light to moderate and wind velocity ranged from 300 to 500 feet per minute. The muzzle elevation was less than 200 mils on all shots and the muzzle blast produced a cloud with an average duration of 14 seconds. Concentration was 1.3 mg/ft^3.

Marching Troops - 250 troops produced a dust cloud measured at 0.02 mg/ft^3 for 275 seconds at a distance of 77 feet. They were walking on a sand and gravel road with approximately 1/2 to 1-inch of loose material. Other troops walking over loose soil, 8 per cent less than 0-74 microns, produced a 0.3 mg/ft^3 dust cloud at 50 to 100 foot distances.

Wind - 1000 to 1200 foot per minute wind speeds produced an occasional dust concentration up to 0.4 mg/ft^3 in an open field with scrub vegetation.

Convoys - Dust produced by two convoys of mixed vehicles moving at 15 miles per hour and ranging in size from 1/4-ton to heavy tractor trailer units was sampled. One convoy consisted of 27 vehicles and the other 26. Concentrations were measured at .09 and .11 mg/ft^3. Wind velocity was 1200 feet per minute, the terrain slightly dusty, and the sampler distance 27 feet.

General Traffic - Several measurements were made of general traffic with light wind speeds. Road surfaces were compacted material and the sampler distances 18 to 50 feet. Concentrations ranged from 0.02 to 0.07 mg/ft^3.

Drone Launch - A number of attempts were made to measure concentrations produced by missile launchings. None was successful because of cancellations, delays, hard stand launchings, etc. Two concentration measurements were made during the launchings of MQN61-A drones which were boosted with one JATO bottle. The launching surface was hard packed sand and gravel having an 8.3%, 0-74 micron particle content. Wind velocity varied from

500 to 1000 feet. One launch produced a 28 second cloud having an average concentration of 0.9 mg/ft^3 at a distance of 67 feet; the other produced a 17 second cloud with a 2.4 mg/ft^3 concentration at 90 feet.

VI. SUMMARY

The variance of the dust environment is such that almost any type of conclusion can be supported by inappropriate data selection. Conversely, conclusions which include all data points are almost impossible to develop. Therefore, careful attention to many factors is necessary to gain a more accurate understanding of the subject.

Visibility was found to correlate with concentration reasonably well and data are probably sufficient to allow reasonable estimations of concentration from visibility observations. Visibility was independent of the types of dust sampled.

Concentration is affected by particle size of surface soil and state of agglomeration. It may be almost linear with the percentage of soil particles between 0 and 74 microns if the surface agglomeration is the same. Sufficient dust sized particles exist in many soils to produce heavy dust concentrations. Vehicular traffic is adequate to deagglomerate or break almost all soil types and produce appreciable percentages of dust particles.

The duration of the dust cloud produced by a vehicle is difficult to establish but will range from 4 to 25 seconds most of the time. Wind speed, distance from vehicle and size of generated plume are undoubtedly influential factors but precise correlation could not be obtained.

The factors affecting concentration are so many that it is impractical to evaluate individual factor effects. A considerable range of dust producing situations was found and by referring to the data it is possible to obtain an estimation of likely concentrations under similar conditions.

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13. ABSTRACT

Measurement of the dust environment was conducted at five military installations in the southwestern United States. The purpose of these measurements was to establish the important characteristics of the dust clouds which would be experienced by stationary equipment in the vicinity of various types of military activity. The main emphasis was placed on vehicular created dust clouds although some data were gathered from other dust producing situations.

The results showed a very wide variation indicative that many factors can and do influence the dust environment. The data were sufficient and support several broad generalizations regarding some effects on cloud duration visibility and concentration.

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