Background Report Reference

AP-42 Section Number: 9.9.1

Background Report Section: 4

Reference Number: 12

Title: Grain Dust Levels Caused By Tent Control Of Ship Loading Emissions Compared To Minimum Explosive Levels

GCA Corporation

December 1978

AP-42 Section 9.9.1
Reference
Report Sect. 4
Reference 12

GCA/TECHNOLOGY DIVISION

GCA-TR-78-75-G

FEASIBILITY OF CONTROL OF PARTICULATE
EMISSIONS FROM GRAIN TERMINALS

Contract No. 68-01-4143
Technical Service Area 1
Task Order No. 47

EPA Project Officer

Mr. John R. Busik
Division of Stationary Source
Enforcement
401 M Street, S.W.
Washington, D.C. 20460

EPA Task Officer

Mr. Norman Edmisten
U.S. EPA,
Oregon Operations Office
522 S.W. Fifth St.
Yeon Building
Portland, Oregon 97204

GRAIN DUST LEVELS CAUSED BY TENT CONTROL OF SHIP LOADING EMISSIONS COMPARED TO MINIMUM EXPLOSIVE LEVELS

Draft Final Report

by

William Battye

Robert R. Hall

Pedro Lilienfeld

Thomas Michel

GCA CORPORATION
GCA/TECHNOLOGY DIVISION
Bedford, Massachusetts

December 1978

U.S. ENVIRONMENTAL PROTECTION AGENCY
Division of Stationary Source Enforcement
Washington, D.C. 20460

DISCLAIMER

This Draft Final Report was prepared for the Environmental Protection Agency by GCA Corporation, GCA/Technology Division, Burlington Road, Bedford, Massachusetts 01730, in fulfillment of Contract No. 68-01-4143, Task Order No. 47. The opinions, findings, and conclusions expressed are those of the authors and not necessarily those of the Environmental Protection Agency. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

ABSTRACT

Recent explosions in grain handling facilities have generated considerable concern with respect to any operation where grain dust is generated and contained. As a result of this concern, tarpaulins are no longer used to control particulate emissions from ship loading at the Bunge and Louis Dreyfus terminal grain elevators in Portland, Oregon. This has resulted in an increase in the particulate emission factor for ship loading at these facilities from about 6g/1000 kg (13 lb/1000 long tons) of grain loaded to about 40g/1000 kg (88 lb/1000 long tons). The purpose of this study was to determine whether the use of tarpaulins at the Bunge and Dreyfus ship loading facilities would, in fact, pose an explosion hazard. Measurements of dust concentration and other parameters related to explosibility were made in the holds of ships at the United Grain terminal at Tacoma, Washington both during tent controlled loading and during uncontrolled loading. Both loading and weather conditions during these tests were similar to typical conditions at the Bunge and Dreyfus terminals. The highest dust concentration found during tent controlled loading was 2.3 g/m^3, which is at least a factor of 8 below the lower explosive limits for wheat grain dust cited in the literature - 20 to 100 g/m^3. The average dust concentration measured for tent controlled loading with a typical aspiration rate of 225 m^3/min (8000 cfm) was 0.29 g/m^3. This is at least a factor of 70 below the lower explosive limit, and is only a factor of 1.6 higher than the average dust concentration measured during uncontrolled loading - 0.18 g/m^3. The average dust concentration found during tent controlled loading was a strong function of the air aspiration rate. The average concentration measured with no aspiration was 0.86 g/m^3, which is a factor of 3 higher than the average with an aspiration rate of 225 m^3/min (8000 acfm).

CONTENTS

FIGURES

TABLES

SECTION 1

INTRODUCTION

Explosions in grain elevators in late 1977 and early 1978 caused considerable concern with respect to any operation where dust, particularly grain dust, is generated and contained.

Ship loading at terminal grain elevators results in the aerosolization of dust formed by abrasion of the grain in numerous transfer operations. The dust becomes aerosolized when the grain is dropped down long chutes (15 to 25 m, or 50 to 80 ft) into the ship holds. Preventing the emission of this dust requires proper control equipment design because of variations in ship and hold sizes, and because deck height will vary not only with tide or river level but with ship trim as well.

One method of controlling dust emissions during ship loading involves covering of the hold opening with tarpaulins, and aspiration of dust laden air under the tents to a fabric filtration system. At most terminals using tents, the tents are used only during general filling of bulk carriers, since they may interfere with loading operations if used during topping off or during tween-decker loading and are not needed for tanker loadings. Bulk carriers carry some 90 percent of the grain shipped in the United States, however, and 85 to 95 percent of the grain loaded to these is loaded in a general filling mode. Use of tents to control emissions from bulk carrier loading results in a reduction of the particulate average emission factor (including topping-off) from about 40 g/metric ton (13 lb/1000 long tons) loaded to 2 to 10 g/metric ton (4 to 21 lb/1000 long tons.)[1]

Before early 1978, tents were used to control emissions from ship loading at the Bunge and Dreyfus terminal grain elevators in Portland, Oregon. In early 1978, the use of the tents generated concern among Portland longshoremen, as they were thought to cause an explosion hazard by causing increases of dust concentration in the holds. The tents are not used presently by the longshoremen although they are still made available by the elevator operators.

This report describes tests made by GCA/Technology Division for the Environmental Protection Agency, Oregon Office to determine whether the use of tents to control dust emissions during ship loading would pose an explosion hazard, particularly at the Bunge and Dreyfus terminals. Since tents are not presently used at these elevators, it was necessary to perform these tests at the United Grain terminal in Tacoma, Washington. Tents are still in use at this elevator, and the elevator is similar in many respects to the two elevators of interest in Portland. First, the loading chutes at the three elevators are similar, being about 15 m (50 ft) long with the capability to telescope about

6 m (20 ft). Also, all three elevators use slanted, rather than vertical chutes. The loading rates used at the three terminals are similar; United Grain generally loads at a rate of about 750 tons (metric tons or long tons)/hr, while Bunge and Dreyfus loaded at rates of 1200 t/hr, and 1000 t/hr, respectively. The tents used at United Grain are lighter and easier to handle than those available at Bunge and Dreyfus, however they still serve to cover the hold and contain the dust. The aspiration capability at the United Grain terminal is 280 m^3/min (10,000 cfm), which is the same as the capabilities at the Bunge and Dreyfus terminals. Finally, weather conditions at Tacoma are very similar to those at Portland, especially with regard to the moisture content of the air; which may have some influence on dust generation and explosibility.

Since the Portland grain terminals load almost exclusively wheat, it was determined that the United Grain tests would be conducted while the elevator was loading wheat. The tests were conducted November 27, 28 and 30, while the elevator was loading western white wheat to a typical Japanese bulk carrier. Weather conditions were typical of the area, with temperatures of 10 to 15°C (50 to 60°F), occasional light rain, and relative humidity about 50 to 60 percent.

SECTION 2

BACKGROUND INFORMATION: CONDITIONS REQUIRED FOR DUST EXPLOSIONS

A dust explosion is a reaction in a mixture of finely divided particles and a gas (generally air) which is initiated by a local heat source. For an explosion to occur, the simultaneous presence of an "explosible" dust cloud and an ignition source of sufficient magnitude is required. The explosibility of a dust cloud in air is determined by a number of factors, including type of dust; its concentration; the moisture content of the air and the dust; the flow dynamics and dimensions of the dust cloud; and the extent to which it is contained.[2]

Dust concentration has a profound effect on explosibility. In fact, for a given dust, there is a minimum concentration below which an explosion cannot occur. It should be understood that at dust concentrations below this level it is essentially impossible to initiate an explosion even if an active flame exists within the dust cloud. In this case, only those particles which come in contact with the flame will burn, as there is insufficient heat transfer to ignite neighboring particles.

The precise minimum concentration at which an explosion can be initiated cannot be specified with complete certainty because of the many other factors that influence explosibility. Based on laboratory investigations by several researchers, however, it appears that one can infer a consensus on the minimum explosible concentration for a given dust. Table 1 summarizes values obtained from several sources for the minimum explosive concentration of wheat dust:

TABLE 1. MINIMUM MASS CONCENTRATIONS REQUIRED FOR WHEAT DUST EXPLOSIONS[2]

Mass concentration (g/m^3)	20 - 50	40	10.3	50 - 100	23	70
Literature source (reference)	3	4	5	6	7	8

The low value of 10.3 g/m^3 from Reference 5 probably resulted from the experimental method used for that determination which frequently yields underestimates of the minimum explosive concentrations.[3] It thus appears that the averate minimum concentration for the other sources is about 40 g/m^3 with a low limit of about 20 g/m^3. Table 2 lists minimum explosive concentrations measured for other agricultural dusts.[9] This tends to confirm the 40 g/m^3 average minimum.

TABLE 2. MINIMUM EXPLOSIBLE DUST CONCENTRATION OF AGRICULTURAL GRAINS[9]

Type of dust	Minimum explosible concentration (g/m^3)
Alfalfa	100
Coconut shell	35
Coffee	85
Coffee, instant	280
Corn cob	45
Cornstarch	40
Cottonseed meal	55
Malt barley	55
Rice	50
Soya flour	60
Soya protein	50
Sugar	45
Wheat flour	50
Wheat starch	45
Yeast	50

As would be expected, moisture tends to reduce the explosibility of dust, and the effect is shown by increases in the minimum explosible mass concentration and minimum ignition energy. Typically, the minimum dust concentration for explosibility increases by about a factor of 10 for admixed moisture concentrations of the order of 100 g/m^3, with respect to explosible dust concentrations at zero moisture levels.[9] Similarly, it has been determined that grain dust explosions are inhibited for dust moisture content in excess of about 20 percent.[3] It can thus be stated that small amounts of water adsorbed onto the dust particles drastically reduce the danger of explosibility given that the dust concentration is sufficiently high for such a danger to exist.

Particle size also has an effect on the explosibility of a dust cloud. The minimum explosive concentration tends to increase with increasing particle size for two reasons. First, for a given mass concentration, the number of particles increases with decreasing average diameter causing a decrease in the distance between the particles. This facilitates heat transfer between neighboring particles. Second, for a given mass concentration, the total surface area increases with decreasing size, and reaction rates between solids and gases are generally strongly dependent on the contact surface. Figure 1 shows the effect of average particle size on the minimum explosive limit of cornstarch.[10] The limit is constant up to about 100 μm, and increases drastically between 100 μm and 150 μm. Particles smaller than 75 μm are generally used in Bureau of Mines investigations of explosibility of dust clouds.[8] It should be noted that, in practice, the size distribution of dust generated by various means is not extremely variable as particles larger than 100 μm tend to settle out rapidly, leaving only smaller particles.

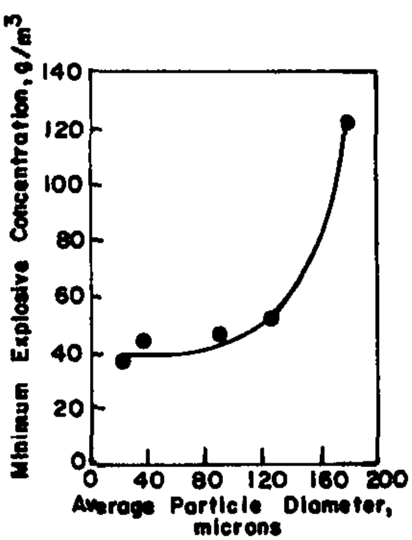

Figure 1. Effect of particle size on the minimum explosive concentration of cornstarch.

SECTION 3

MEASUREMENTS

In order to decide whether the use of tents to control ship-loading emissions poses an explosion hazard, one must determine first whether the tents cause an appreciable change in the character of the atmosphere inside the hold, and second whether the resulting atmosphere is an explosible one. Background material on the conditions necessary for dust explosions indicates that the parameters which are most important in determining the explosibility of a dust cloud are (1) dust concentration, (2) dust size distribution, and (3) moisture. Measurements of dust concentration and relative humidity were made at various locations in the holds during both uncontrolled loading and controlled loading with various aspiration rates. Based on background data on dust explosions (see Figure 1), and on the fact that the Bureau of Mines measures lower explosive limits using particles less than about 75 μm, it was decided that the concentration of only the dust smaller than 75 to 100 μm should be measured. The aspiration rate was changed by removing suction hoses from the hold. These were also measured. Particle size distributions were measured for both tent controlled and uncontrolled loading.

PROCEDURES AND EQUIPMENT

Dust Concentration and Humidity Measurements

Dust concentrations (smaller than 75 to 100 μm or 0.0029 to 0.0039 inch) and humidities were measured by a probe consisting of a remote humidity and temperature sensor and a dust collector designed and built by GCA. The probe can be suspended in a hold by an 18 m (60-foot) umbilical cord which contains shielded cable for the humidity sensor and air and pressure tap lines for the dust sampling device.

Dust Concentration--

The specially designed dust sampling probe is illustrated in Figure 2. Air is drawn through the probe at a predetermined rate by a remote pump. The rate is maintained using a dry gas flow meter and an orifice flow meter. A gravitational preseparator at the inlet of the probe allows only those particles with aerodynamic diameters smaller than 75 to 100 μm to be drawn into the probe. Larger particles tend to have settling velocities greater than the velocity of air in the preseparator, and are, thus, not collected. After passing through the preseparator, the air, with particles smaller than 75 to 100 μm, passes through a filter holder. In the filter holder preweighed glass fiber filters are used to remove the remaining dust from the air. There are pressure taps to the airstream on either side of the filter holder which allow the measurement of the pressure drop across the filter at any instant.

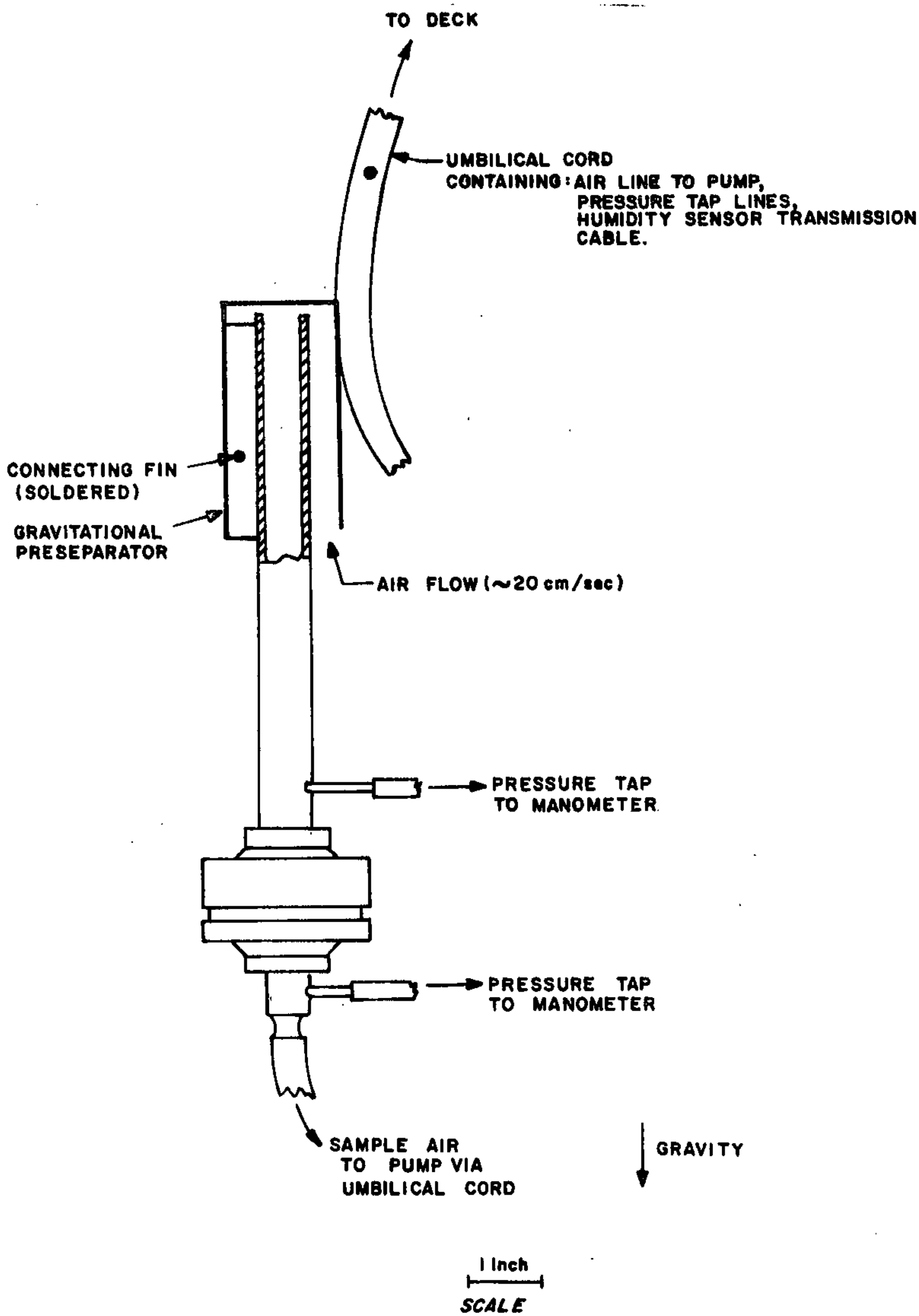

Figure 2. Sampling device for use to measure grain duct concentration in ship holds.

The dust filter was changed every 5 to 20 minutes during the Tacoma tests, and each filter change constituted a run. During each run the pressure drop across the filter was recorded once a minute for the duration of the run. The total number of runs made under various conditions was 25.

From the total volume of air drawn through the filter during a given run, and the dry weight of the filter before and after the run, one can determine the approximate average concentration of suspended particles (< 80 to 100 μm) in the sampled air.

From readings of the pressure drop across the filter at different times during the run, it is possible to determine approximate dust concentrations for shorter time intervals. It has been found that the relationship between the dust cake thickness on a fabric filter control device and the pressure drop across the fabric takes the general form of curve (a) in Figure 3.[11]

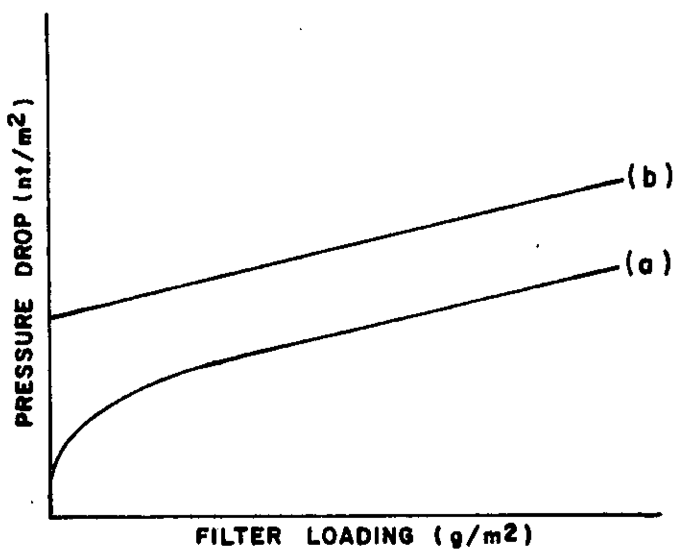

Figure 3. Pressure drop across particulate filters.[11]

For the thick glass fiber filters used in these experiments, the relationship between dust cake thickness and pressure drop across the filter approximates the straight line (b).[12] Thus, one can expect a linear relationship between the rate of increase of the pressure drop across the filter and the rate of dust deposition on the filter. Since the flow rate of air through the filter is maintained at a constant value, the rate of dust deposition is directly proportional to the concentration of particulate matter in the air. To obtain the average dust concentration for a given minute of a given run, then, one need only multiply the average dust concentration over the entire run by the ratio between the rate of pressure drop increase over the entire run.

Relative Humidity--

The remote humidity sensor was obtained from Phys-Chemical Research. The device contains two integrated circuits whose impedance is directly related to the temperature and humidity of the air around them. The circuits in the probe are connected by shielded cable to an indicator box built by GCA, and from which the temperature and humidity can be read. The temperature can be obtained directly from the impedance of one of the circuits, while the impedance of the other, when corrected for temperature, can be used to obtain the relative humidity. In the range of 60 to 90 percent relative humidity, the sensor is accurate to within 2 percent relative humidity.

Relative humidity measurements were made inside and outside the hold for 16 of the dust concentration runs.

Aspiration Rates

For each loading spout at the United Grain terminal there is one aspiration pipe attached to the spout and two flexible aspiration hoses which can be inserted under the tents at the edge of the hold. During loading, the two hoses and the pipe for the loading leg in use are always pulling air to the fabric filtration system. Generally, hoses for other legs are pulling air as well. The aspiration rate was adjusted during the course of the measurements by putting different numbers of hoses into the hold being loaded, or by turning off the suction system entirely. Aspiration rates for individual tubes were measured by GCA using a pitot tube. The tube was used to find air velocities at various distances from the center of the tube, and the total flow rates were found using these velocities and tube areas.

Particle Size Measurements

An Andersen particle fractioning sampler ("Andersen impactor") was used to obtain typical particle size distributions during tent controlled loading and also during uncontrolled loading (topping off).

As in the suspendable dust collection probe described above, air is drawn through an Andersen impactor at a predetermined rate by a remote pump. Again the sampling rate is maintained constant by a dry gas flow meter and an orifice flow meter. The impactor itself contains eight plates mounted in series, each having a pattern of precision-drilled orifices. The orifices are smaller for successive stages. Generally, a cyclonic preseparator and a backup filter are mounted at the inlet and outlet of the impactor, respectively. Large particles are removed from the sample air stream by the cyclonic precollector. Smaller particles are inertially impacted onto eight preweighed glass fiber substrates which are mounted below the precision-drilled plates. The aerodynamic size ranges of the particles deposited in the precollector and on the eight substrates can be calculated using the exact flow rate of air through the impactor and constants which are determined by the precollector dimensions and the diameters of the precision-drilled orifices. Particles which pass through the precollector and the impactor are trapped on the backup filter. Thus, dust entering the impactor-precollector-filter system is fractioned into ten size ranges. There are effectively nine size ranges, however, since the cutoff diameter for the precollector is lower than that for the first impaction plate. From the dry weight of the dust trapped in the precollector, and the dry weights of the eight substrates and the backup filter before and after a run, one can determine the total average dust concentration in the sampled air; and the size distribution of the dust.

An Andersen impactor is generally used to sample gas flowing out of a stack. When this is done, the inlet nozzle for the precollector is chosen so that, when the impactor is run at the desired flow rate, the gas velocity through the orifice will be the same as the gas velocity in the stack. Since there is no constant airflow velocity or direction in the hold of a ship, this procedure could not be used. Instead, the nozzle size was chosen to minimize the airflow velocity through the nozzle and, thus, keep the collection efficiency for different size particles relatively constant. The impactor was held in such a way that the nozzle was mounted horizontally. It is estimated that particles up to about 150 μm (0.0059 in.) are collected using this technique, with collection efficiency becoming smaller as particle size increases.

RESULTS

Size Distribution

The results of Andersen impactor measurements of particle size distributions are presented in Table 3 and Figure 4. Two runs were made, one during tent-controlled loading with an aspiration rate of about 225 m^3/min or 8000 cfm (run A1), and one during uncontrolled loading (run A2). In each case, the impactor was located in a moderately dusty section of the hold, somewhat removed from the grain impaction site. Figure 4 shows that the size distributions found in the two runs are essentially the same. The mass median diameter of the suspended particles was about 11 μm (4.33×10^{-4} in.) while the geometric standard deviation was about 3.2. Particles larger than 80 to 100 μm made up an insignificant fraction of the particles collected by the impactor.

Aspiration Rates

Aspiration rates for open hoses and tubes were measured during the loading of one hold. There was one aspiration tube attached to the loading spout, and two tubes which would reach the hold being loaded. These three tubes must be on or off in unison. The tube about the spout was found to pull air at a rate of 160 m^3/min (5700 cfm), while each flexible hose pulled at a rate of 70 m^3/min (2500 cfm). Three flexible tubes which would not reach the hold being loaded were valved open, but were placed end to the ground so that no air was drawn through them. The measured total amount of air being drawn through the fabric filtration system was, then, 300 m^3/min (10,700 cfm).

Relative Humidity

The results of relative humidity measurements are presented in Table 4. The table also indicates the general conditions under which the measurements were taken. Aspiration rates were estimated by considering which tubes were in use and the aspiration rates measured for such tubes. It is assumed that the aspiration rate for flexible hoses and the tube above the loading spouts are the same regardless of which loading spout is in use.

There does not appear to be a significant dependence of the humidity in the hold with whether or not tents are in use. There is some dependence of

TABLE 3. PARTICLE SIZE DISTRIBUTION

Run no.	Time (min)	Air sampled (acf)	Total concentration (xg/m^3)	Weight percent less than stated size*							
				Cyclone	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Stage 6	Stage 7
A1	7	0.897	0.29	70.5 (19.6)	57.2 (16.4)	39.0 (11.2)	34.5 (7.63)	24.5 (4.75)	17.0 (2.10)	8.70 (1.44)	1.74 (0.883)
A2	7	1.011	0.18	68.3 (18.4)	62.6 (15.4)	44.7 (10.5)	28.2 (7.16)	19.1 (4.46)	9.72 (1.96)	5.64 (1.35)	0 (0.825)

*Numbers in parenthesis are sizes in microns. Top numbers are percentages less than the stated sizes.

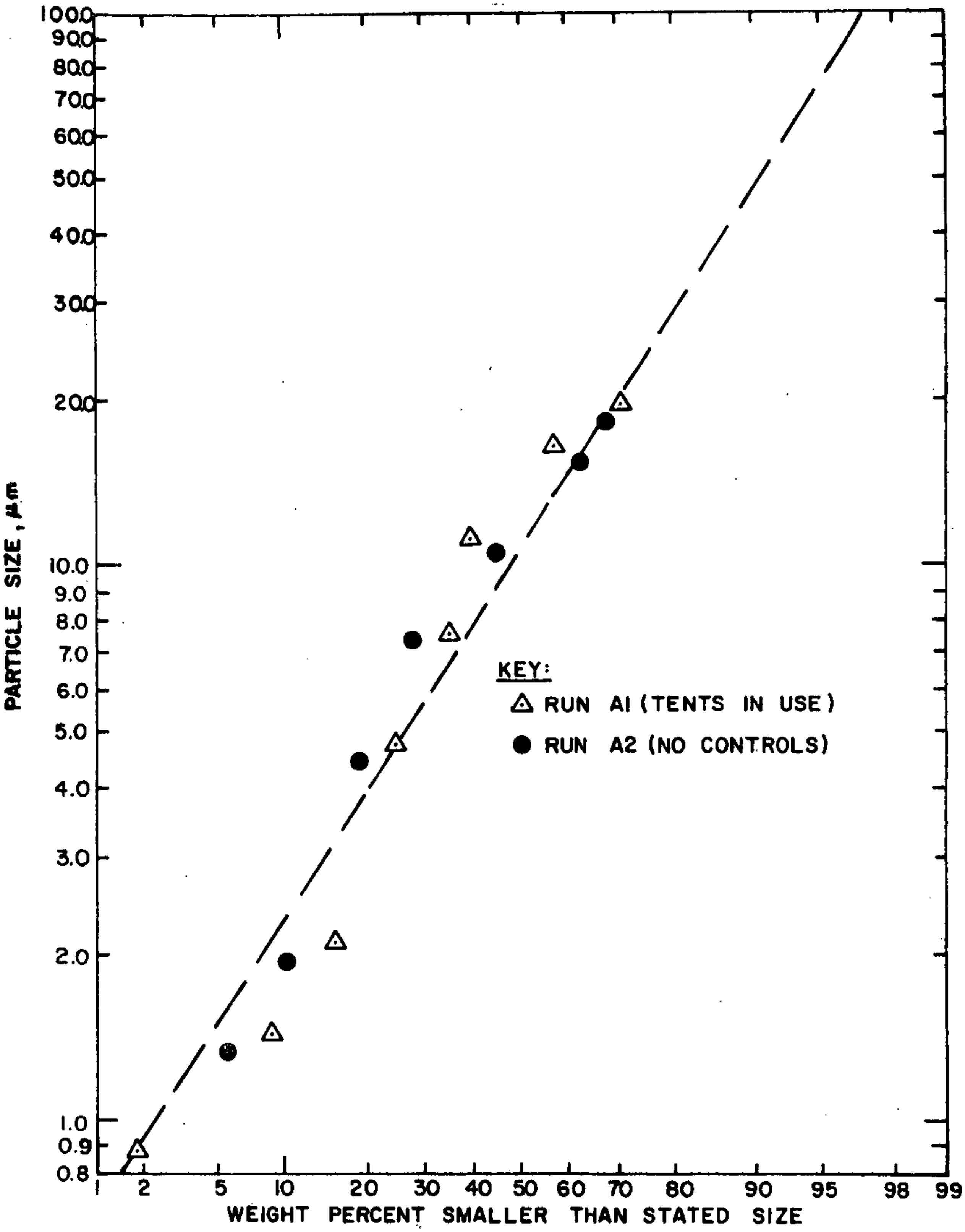

Figure 4. Particle size distribution.

TABLE 4. RELATIVE HUMIDITY RESULTS

Run code	Relative humidity (percent)		Difference	Conditions	
	Outside hold	Inside hold		Tent in use? (x)	Aspiration rate (m^3/min)
1	60	63	+3	X	225
2	63	61	-2	X	225
3	63	59	-4	X	225
4	63	58	-5	X	225
5	63	58	-5	X	160
11	62	63	+1	X	0
12	62	62	0	X	0
13	62	59	-3	X	160
15	68	70	+2	X	160
16	68	70	+2	X	160
20	82	82	0		-
21	82	73	-9		-
22	82	73	-9		-
23	82	73	-9		-
24	80	70	-10		-
25	70	72	+2	X	0

the difference between inside and outside humidity on outside humidity. For outside humidities of 72 percent and less, the humidity inside the hold was, on the average, only about 1 percent less than that outside. For outside humidities of 80 percent and above, the humidity inside the hold was on the average 7 percent below the outside humidity. This was true even when no tent was used. In any case, the humidity inside the hold is not appreciably lower than that outside the hold.

Suspended Particulate Concentrations

As was previously mentioned, 25 measurements of suspended (< 80 to 100 μm) dust concentrations were made during topping-off and during tent controlled loading with different aspiration rates at various locations in the holds. Since nearly all of the particulate matter collected in the two Anderson impactor runs was smaller than 80 to 100 μm (see Figure 4), the total dust concentrations measured in these runs should also be considered in any determinations of average suspended dust concentrations.

Average dust concentrations have been calculated for each run and, where possible, concentrations for each minute have been estimated. One minute average concentrations could not be found for Anderson impactor runs, or for suspended dust runs where the average concentration for the entire run was less than about 0.5 g/m^3, since pressure drop increases were too small to be accurately measured. The results of dust concentrations calculates are presented in Table 5 and summarized in Table 6. The figures indicate during which runs tents were in use, and give estimated total aspiration rates. Figure 4 also indicates for each run whether the measuring device was located in a particularly dusty, particularly clear, or typically dusty area of the hold. These indications are based on visual observations.

The location of the probe or Anderson impactor with respect to the grain spout, the grain level, the impact site of the falling grain, and the sides and top of the hold is illustrated roughly for each test in Figure 5. Since the locations of the above landmarks were not the same for all of the runs, Figure 5 contains six illustrations, each of which shows the probe location for one or more runs. The placement of the loading spout, etc., in each of the six illustrations represent an average for the different runs described by the illustration. Figure 5(a) to (c) show probe locations for runs where tents were in use, while Figure 5 (d) to (f) illustrate probe locations during topping-off or uncontrolled loading. The figure shows aspiration hose locations where the hoses were in use. The fact that a hose appears in a given illustration, however, does not imply that the hose was present for all of the runs for which probe locations are illustrated. (Refer to Table 5 for which hoses were in use for various runs.)

Table 6 shows that, in general, dust concentrations measured during tent controlled are somewhat higher than those measured during uncontrolled loading or topping off. Also, for runs made during tent controlled loading, a marked dependence of dust concentration on aspiration rate can be inferred. For ten controlled loading at an aspiration rate of 225 m^3/min (8000 cfm), the average

TABLE 5. RESULTS OF DUST CONCENTRATION MEASUREMENTS

Run	Date	Time	Duration	Visual observation of probe area*	Tents in use (x)	Aspiration rate m³/min	Hoses in use†	Average dust level (g/m³)	Estimated 1 min average concentrations for given minutes (g/m³)																
									1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	10/27	11:35	15	D	X	225	A, B	0.02																	
2		13:30	7	D	X	225	A, B	0.34																	
3		14:05	15	D	X	225	A, B	0.11																	
4		14:26	15	D	X	225	A, B	0.07																	
5		14:48	20	T	X	160	A	0.08																	
7		15:55	12	T	X	160	A	0.45																	
8		16:15	15	T	X	160	A	0.18																	
9	10/28	08:50	6	T		-	-	0.18																	
10		09:30	10	T	X	0	-	0.83	0.4	0.4	0.4	0.4	0.6	1.5	1.5	1.5	1.5	1.5							
11		09:45	10	T	X	0	-	0.82	0.3	0.3	0.3	0.9	0.7	0.6	0.9	0.7	0.7	(2.2)‡							
12		10:00	10	T	X	0	-	0.75	0.4	0.4	0.5	0.9	0.7	0.9	1.1	1.3	0.5	0.7							
13		10:15	17	T	X	160	A	0.66	0.6	0.6	0.6	1.0	0.7	1.0	1.0	0.7	0.7	0.6	0.4	0.5	0.5	0.5	0.6	0.7	0.7
14		10:35	13	T	X	160	A	0.30																	
15		11:10	15	D	X	160	A	0.38																	
16		11:40	10	T	X	160	A	0.18																	
17		13:24	2	T	X	160	A	0.61																	
A1		14:30	7	T	X	225	A, B	0.29																	
18		15:00	12	T	X	225	A, B	0.87	–	0.4	0.3	0.3	0.4	0.6	0.6	0.9	1.2	1.0	1.2	2.3					
19		15:13	10	D		-	-	0.75	(0.02)‡	(1.7)‡	0.7	0.7	0.6	1.0	0.9	0.5	0.3	0.3							
A2	10/30	08:15	7	D		-	-	0.18																	
20		08:44	10	T		-	-	0.04																	
21		09:05	15	T		-	-	0.17																	
22		09:20	15	T		-	-	0.01																	
23		09:40	6	T		-	-	0.02																	
24		09:52	1.83	T		-	-	0.02																	
25		10:30	7	D	X	0	-	1.1	0.7	1.2	1.2	1.0	1.0	1.2											

*D = Dustier than the rest of the hold
T = Typical

†A = Pipe attached to grain spout
B = One flexible hose

‡Pressure drop data used to estimate these values may be questionable.

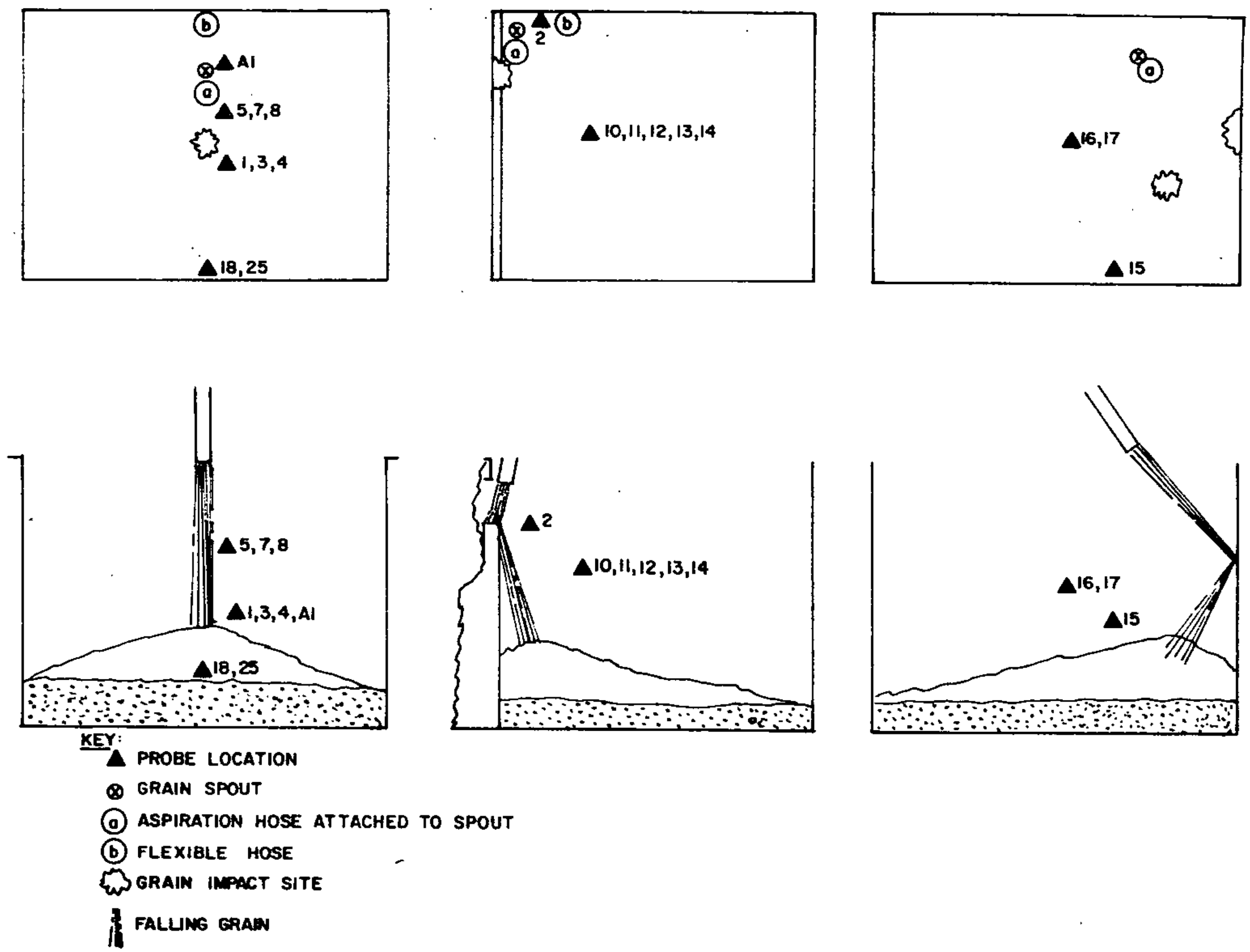

Figure 5. Measuring probe locations.

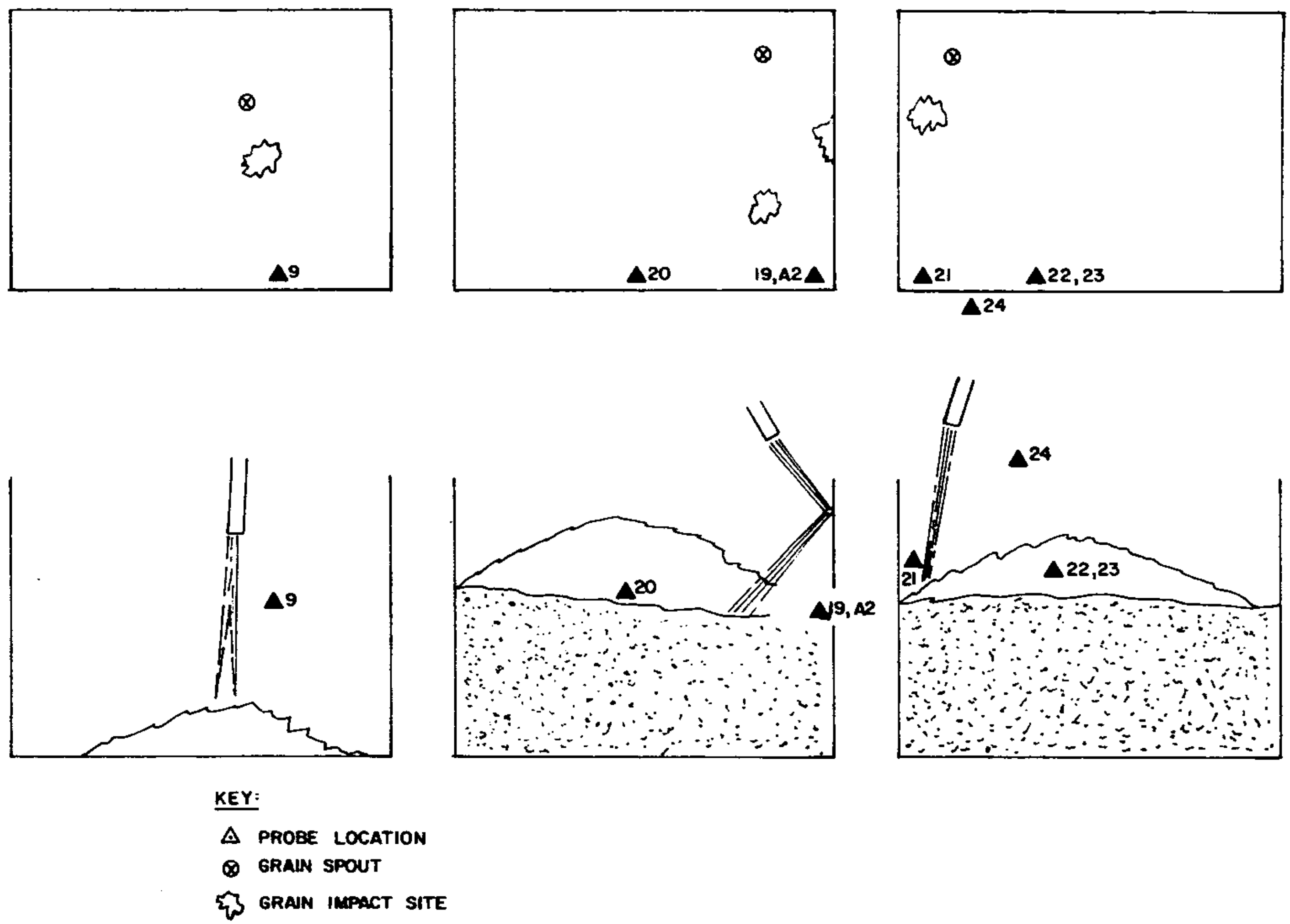

Figure 5. (Continued)

TABLE 6. SUMMARY OF DUST CONCENTRATION RESULTS

Conditions	Number of runs	Average concentration measured (time weighted) (g/m^3)	Maximum long-term average concentration (g/m^3)	Maximum estimated average concentration (g/m^3)
Tents in use - Aspiration rate: 225 m^3/min	6	0.29	0.87	2.3
- Aspiration rate: 160 m^3/min	8	0.32	0.67	1.0
- Aspiration rate: 0 m^3/min	4	0.86	0.83	(2.2)*
Tents not in use	8	0.18	0.75	(1.7)†

*Questionable value. The next highest estimated 1 min average concentration in this body of data is 1.5 g/m^3.

†Questionable value. The next highest estimated 1 min average concentration in this body of data is 1.0 g/m^3.

dust concentration measured is only 60 percent higher than the average concentration measured during uncontrolled loading, while the average concentration measured during controlled loading with no aspiration is 380 percent higher than that measured during uncontrolled loading. No relationship can be inferred between maximum 1-minute dust concentration and aspiration rate, or whether tents are in use.

SECTION 4

DISCUSSION AND CONCLUSIONS

The highest suspended dust concentration found for tent-controlled loading at the United Grain facility was 2.3 g/m^3. This is at least a factor of eight below the lower explosive limit for dry grain dust — 20 to 100 g/m^3. This level was measured in a localized area for a short period of time — 1 min. In fact, 1 min average concentrations nearly as high — 0.96 to 1.7 g/m^3 — were measured in localized areas during uncontrolled loading. The average dust concentration measured during tent controlled loading with typical aspiration — about 225 m^3/min (8000 cfm) — was only 0.29 g/m^3. This is at least a factor of 70 below the lower explosive limit, and only a factor of 1.6 higher than the average dust concentration measured during uncontrolled loading — 0.18 g/m^3.

Even if an explosion was possible, an ignition source was present and an explosion was initiated, the effects would be limited by the minimal containment. The tarpaulin would tend to lift off the hatch and vent any explosion before significant pressure buildup.

When tents were used, a strong dependence of dust concentration on aspiration measured for tent controlled loading with no aspiration was 0.86 g/m^3, which is a factor of three higher than the average for loading with a typical aspiration rate of 225 m^3/min (8000 cfm).

The difference between the relative humidity inside the hold and that outside the hold was found to be negligible. This would tend to imply that the grain dust was not completely dry when formed. Any moisture in the grain or in the air would tend to reduce the danger of an explosion even if the dust concentration is sufficiently high for such a danger to exist.

The conditions under which these measurements were made are very similar to typical loading conditions at the Bunge and Louis Dreyfus terminal grain elevators in Portland, Oregon. Weather conditions, especially relative humidity, are similar. Also, the United Grain terminal in Tacoma uses a loading system similar to those in use at the Bunge and Dreyfus terminals. All three terminals have slanted loading spouts about 0.5 meters (20 in.) in diameter and 15 meters (50 ft) long. Loading rates are comparable. The tents used at the United Grain terminal are lighter than those which would be used in Portland, however, they have the same effect, as they completely cover the holds. The ship being loaded at the United Grain terminal during the test was a bulk carrier; and the grain being loaded was wheat. The Bunge and Dreyfus terminals load bulk carriers and handle wheat almost exclusively.

REFERENCES

1. Battye, W., and R.R. Hall. Feasibility of Control of Particulate Emissions from Grain Elevators (Draft Report in preparation). GCA/Technology Division, EPA Contract No. 68-01-4143, Technical Service Area 1, TO No. 47. January 1979.

2. Lilienfeld, Pedro. Special Report on Dust Explosibility. GCA/Technology Division, GCA-TR-78-17-6. EPA Contract No. 68-01-4143, Technical Service Area 1, Task Order No. 24. March 27, 1978.

3. Gooijer, H. de, et al. Literature Investigation into the Dust Explosion Danger in Industries Storing and Processing Cereals and Flour, TNO Report 8398 Rigswijk, Netherlands. October 1975.

4. Grain Elevator Industry Hazard Alert, OSHA, January 5, 1978.

5. Beyersdorfer, P. Staub-Explosionen, Verlag von Theodor Steinkopff, Leipzig, 1925.

6. Schierwater, F.W., Die Konzeption der neuen Explosionsschutz-Richtlinien, insbesondere im Hinblick auf die Schutzmassnahmen gegen Staub expllsionen, Staub. 36:43. 1976.

7. Weber, R., Verh, Ver. Beforderung Gewerbefleiss, p. 83. 1878.

8. Marks, L.S. (ed.). Mechanical Engineers Handbook, Sixth Edition. McGraw-Hill. New York. 1958. p. 7 - 44.

9. Palmer, K.N., Dust Explosions and Fires, Chapman and Hall, London. 1973.

10. Hartmann, I., A.R. Cooper, and M. Jacobson. U.S. Bureau of Mines, R.I. 4725. 1950.

11. Dennis, R., R.W. Cass, D.W. Copper, R.R. Hall, V. Hampl, H.A. Klemm, J.E. Langley, and R.W. Stern. Filtration Model for Coal Fly Ash with Glass Fabrics. GCA/Technology Division, Bedford, Massachusetts. EPA-600/7-77-084. August 1977.

12. Consultation with R. Dennis, GCA/Technology Division, Bedford, Massachusetts.

GCA/TECHNOLOGY DIVISION

BURLINGTON ROAD, BEDFORD, MASSACHUSETTS 01730 / PHONE: 617-275-9000