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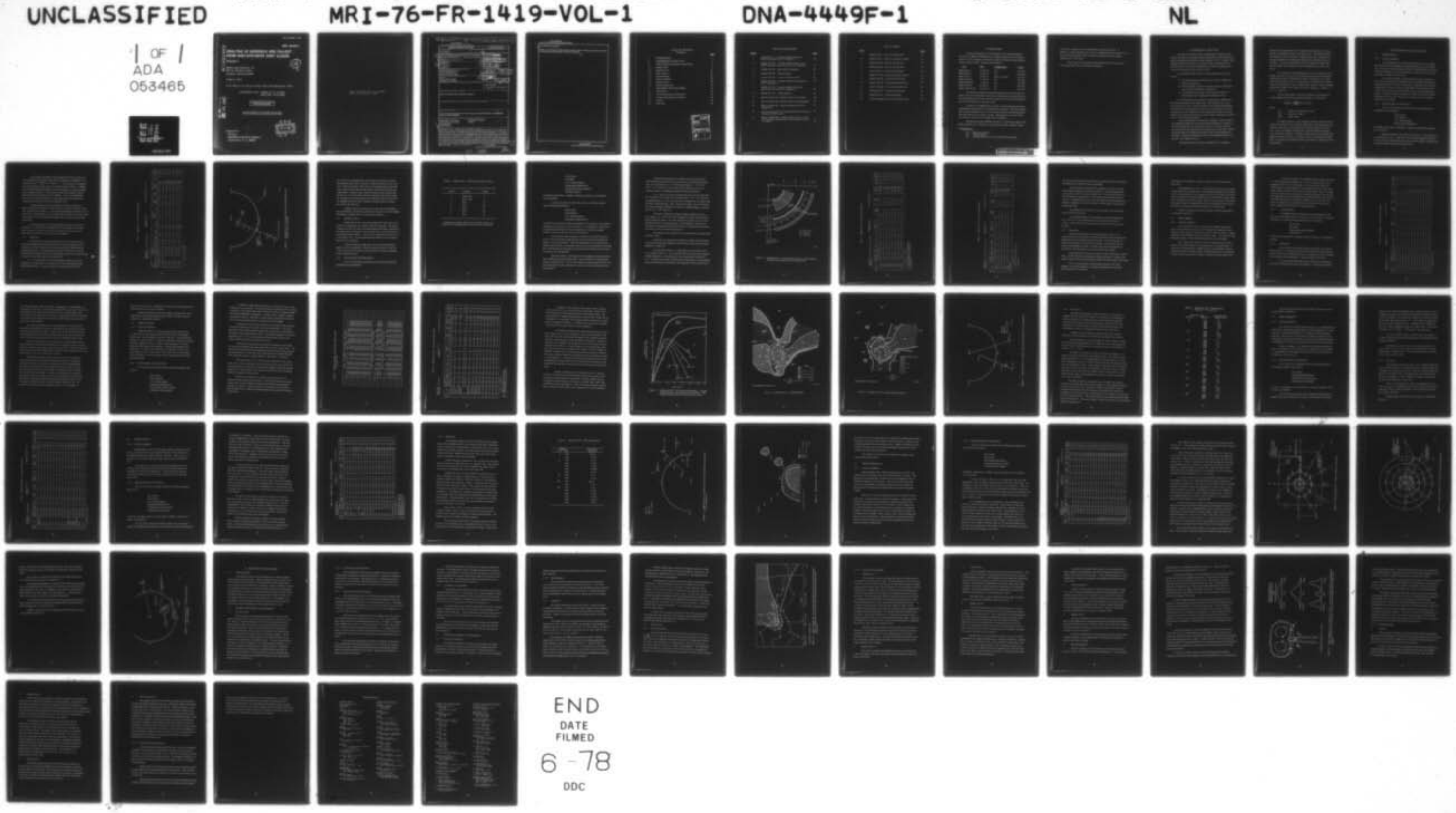

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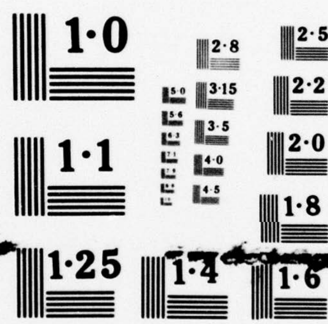

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ANALYSIS OF AEROSOLS AND FALLOUT FROM HIGH-EXPLOSIVE DUST CLOUDS

Volume I

Meteorology Research, Inc.
464 W. Woodbury Road
Altadena, California 91001

3 March 1977

Final Report for Period 3 May 1971—30 September 1973

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Dust clouds from seven high-explosive detonations ranging from 20 to 500 tons in the Middle Gust-Mixed Company series were sampled using various aircraft-mounted instruments. A wet cyclone system proved to be the best device for sampling airborne dust. Dust concentrations as a function of time and location in the clouds were determined. One cloud was underflown as early as Z + 1:22, and another was entered at Z + 1:36. Fallout was measured on three tests, and various experiments were conducted to detect sweepup of dust from outside the crater zone. Gas samples were collected and analyzed from inside the 500-ton Mixed Company III cloud. Selected airborne dust and fallout → next page

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20. ABSTRACT (Continued)

samples were sized using an optical image processing computer. Density measurements were made to determine if particles expanded or melted in the fireball.

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1. INTRODUCTION

Between September 1971 and November 1972, Meteorology Research, Inc. (MRI), participated in seven high-explosive tests conducted by the Air Force Weapons Laboratories under the direction of the Defense Nuclear Agency (DNA). Specific tests included:

Test	Date	Configuration*	Yield
Middle Gust I	16 Sept 71	R-0	20 Tons
Middle Gust II	14 Dec 71	R-2	100 Tons
Mine Throw I	15 Dec 71	Surface Coupled	120 Tons
Middle Gust III	13 Apr 72	R-1	100 Tons
Mixed Company I	1 Jun 72	R-0	20 Tons
Middle Gust IV	22 Jun 72	R-1	100 Tons
Mixed Company III	13 Nov 72	R-1	500 Tons

The primary purpose of the MRI participation was the characterization of the dust environment shortly after detonation to determine the spatial distribution of dust in the cloud and changes in the mass concentration and size distribution as a function of time.

In order to accomplish this objective, special large-particle dust sampling instruments had to be developed and evaluated. This instrumentation was flown primarily on a C-45 aircraft provided by the Environmental Protection Agency (Las Vegas, Nevada). Penetrations of the dust cloud were made as early as 1-1/2 minutes after detonation.

During several tests (Middle Gust III, IV, and Mixed Company III), fallout samples were collected on a predetermined grid, weighed, and in

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* - Configuration:

R-0 Half-buried sphere
R-1 Tangent sphere.
R-2 Elevated sphere (one charge radius above ground)

some cases, analyzed for size distribution and specific gravity. In addition, several techniques were tested, including fluorescent particle (F. P.) tracers and sized glass beads, to measure the extent of dust sweepup following rise of the cloud.

Time-laspe and real-time 16 mm photographs were taken on all tests except Mine Throw I and Mixed Company I.

2. EXPERIMENTAL OBJECTIVES

The primary objective of the program was to sample and determine the mass concentration and size distribution of dust particles in clouds created by the detonation of high tonnages of TNT. Ideally, these samples should be collected as a function of time and position in the cloud during the early rapid rise phase when toroidal circulation controls the distribution of dust within the cloud.

To accomplish this objective, three problems had to be addressed:

(1) The safety aspects of placing an aircraft in a highly turbulent environment.

(2) The quantitative collection of large airborne particulates up to several millimeters in diameter.

(3) The method of collecting several samples of dust sequentially during a single pass through the cloud.

The first problem was defined by progressively reducing the time between detonation and initial entry. The earliest entry of the main cloud was at one (1) minute thirty-two (32) seconds during Middle Gust III (100-ton tangent sphere); however, severe turbulence was encountered at two (2) minutes forty (40) seconds at the base of the same cloud on the second pass which put a limit on future attempts to improve on the 1- to 2-minute early entry.

The second problem was solved by adapting a cyclone separator originally designed for commercial dust separation to a large external scoop built into the side of the aircraft. To insure complete recovery of each dust sample and to avoid carryover, the whole system was flushed with an alcohol-water mixture after each penetration of the cloud. Collection efficiency for the system ranged between 93-97 percent. (See Appendix AI-2.)

The third problem led to the development of a continuous sampler which impacted dust on a rapidly moving adhesive-faced tape and then encapsulated it under a thin Mylar film. Functional problems due to blowout around the nozzle resulted in poor time resolution and extreme difficulty in resolving and automatically reducing the data on the tape. As a result, dust particle data were limited to single integrated samples taken during each pass through the main cloud or the stem.

The reduction of data following each test concentrated on quantitative recovery of the dust collected during each pass and subsequent reporting of the dust concentration in terms of grams per cubic centimeter of air sampled. These concentrations are reported as a function of general location in the cloud, altitude above ground, compass heading, and measured width of the cloud at the time of sampling. (Tables 1, 3, 4, 5, 7, 9, and 12.)

The size distribution of selected samples was determined by a video imaging system and reported graphically as a function of

$$\text{Log}\left(\eta_T(i)\ \frac{D(i)}{\Delta D(i)}\right) \text{ vs. Log } D(i)$$

where

$\eta_T(i)$ = number concentration for bins

$D(i)$ = mean size of bins

$\Delta D(i)$ = width of bins.

Secondary objectives of the program included collection of dust fallout on the ground, tracer particle entrainment, and subsequent measurement of the tracer in the cloud due to sweepup outside the crater zone. In one case (Mixed Company III), gaseous detonation products were sampled and analyzed. Analysis of both airborne dust samples and fallout for specific gravity as a function of size was undertaken to determine if the thermal environment caused any melting or expansion of the dust particles.

3. TEST EVENTS AND DATA COLLECTED

3.1 MIDDLE GUST I

3.1.1 General Conditions

On 16 September 1971, Meteorology Research, Inc., participated in the first of the Middle Gust high-explosive tests at the AFWL site, four miles north of Crowley, Colorado. Middle Gust I was a half-buried (R=0) 20-ton TNT shot detonated in a moist sandy clay overlaying shale at a depth of about 13 feet.

The actual detonation was delayed several times during the day due to unfavorable wind conditions and the possibility of blast ducting in the direction of Crowley and Ordway. Detonation late in the day coupled with low stratus clouds at about 4000 feet above ground level created some problems in assessing the success of the ground experiments. Tracking of the dust cloud once it entered the stratus created problems for the aircraft, forcing it to concentrate on the stem protruding below the clouds.

3.1.2 Instrumentation and Experiments

The C-45 aircraft was instrumented with the following dust sampling/sensing equipment:

- Wet Cyclone
- Tape Sampler
- F.P. Drum Sampler
- Integrating Nephelometer

In addition, temperature, turbulence, altitude, and indicated airspeed were recorded.

Initial penetration of the cloud was made at Z + 4:53 followed by a second pass at + 7:39. After that, the dust cloud disappeared into the overcast, and all subsequent passes were made through the trailing stem. All instrumentation functioned satisfactorily.

The maximum quantity of dust sampled by the wet cyclone was 197.2 milligrams on the first pass which computed to an integrated concentration of $7.07 \begin{smallmatrix} +2.09 \\ -1.61 \end{smallmatrix} \times 10^{-8}$ gm/cm^3. Aircraft data and computed dust concentrations for all passes are summarized in Table 1. Altitude was recorded continuously while the general heading was noted manually by the copilot/observer. True airspeed (TAS) was computed from the indicated airspeed and the pressure altitude. In all cases during this test, the entry and exit points were determined when the nephelometer reading exceeded three times the background level.

Ground experiments were limited to six 20 gm releases of fluorescent particles each at 150 feet, 200 feet, 350 feet, 500 feet, 1000 feet, and 2000 feet (Figure 1). Time-lapse photography indicated successful release of the particles at one second before detonation; however, only the particles at 150 feet and 200 feet appeared to become involved in the dust cloud.

Two hundred pounds of Hydro Buff #12 glass beads (63-105 μm diameter) were released by disintegration of the container in the shock wave; however, the bulk of the beads remained on the ground, and no particles were detected in the airborne dust samples.

3.1.3 Discussion

By the time the first and second passes were made, the main cloud had elongated in the NE-SW direction. Dust concentrations were declining at a rate of about 20 percent per minute due to fallout and expansion of the cloud. The third pass was made at the base of the stem (1800 feet above ground level) and all subsequent passes were made through the stem at about 2600 feet above ground level.

F. P. was detected on the drum sampler; however, the best technique for measuring F. P. proved to be a scan of the bottom of the dust separation vials. In the procedure for removing dust from the

Table 1. Middle Gust I - Aircraft and dust data.

Event - MG I
Configuration - R-0 (Half-Buried Sphere)
Yield - 20 Tons

Sampling Aircraft C-45
16 September 1977

Prevailing Wind Direction - ENE

Pass No.	Location	Alt. Above Gz (ft)		Hdg. (deg)	TAS (mph)	Entry (min:sec)	Exit (min:sec)	Criteria* Entry/ Exit	ΔT (secs)	Cloud Width (meters)	Total Dust (mg)	Dust Conc. (x 10^{-8} gm/cc)	Rmks.	Sized	Dens Dist
		Entry	Exit												
1	Main Cloud	3450	3850	120	147 ± 10	$4:53.0 \pm 0.5$	$5:10.0 \pm 0.5$	N/N	17.0 ± 1.0	1117 ± 142	197.2 ± 0.5	$7.07^{+2.09}_{-1.61}$		Yes	Yes
2	Main Cloud	3950	3850	260	148 ± 10	$7:38.9 \pm 0.1$	$8:10.0 \pm 0.5$	N/N	31.1 ± 0.6	2057 ± 179	125.2 ± 0.5	$2.44^{+0.63}_{-0.46}$		Yes	No
3	Stem	1800	1750	360	162 ± 10	$11:08.3 \pm 0.1$	$11:31.6 \pm 0.2$	N/N	23.3 ± 0.3	1687 ± 126	18.1 ± 0.5	$0.430^{+0.115}_{-0.086}$		Yes	No
4	Stem	2450	2650	150	157 ± 10	$12:48.6 \pm 0.1$	$13:05.0 \pm 0.2$	N/N	16.4 ± 0.3	1151 ± 94	20.2 ± 0.5	$0.703^{+0.192}_{-0.144}$		No	No
5	Stem	2650	2650	270	171 ± 11	$14:59.1 \pm 0.1$	$15:37.3 \pm 0.2$	N/N	38.2 ± 0.3	2920 ± 211	39.5 ± 0.5	$0.542^{+0.136}_{-0.099}$		Yes	No
6	Stem	2700	2550	70	181 ± 11	$17:01.2 \pm 0.1$	$17:35.0 \pm 0.2$	N/N	33.8 ± 0.3	2735 ± 190	15.5 ± 0.5	$0.227^{+0.061}_{-0.045}$		Yes	No
7	Stem	2550	2600	250	177 ± 11	$19:52.4 \pm 0.1$	$20:30.7 \pm 0.2$	N/N	38.3 ± 0.3	3030 ± 212	10.5 ± 0.5	$0.139^{+0.039}_{-0.030}$		No	No

* V = Visual; N = Nephelometer

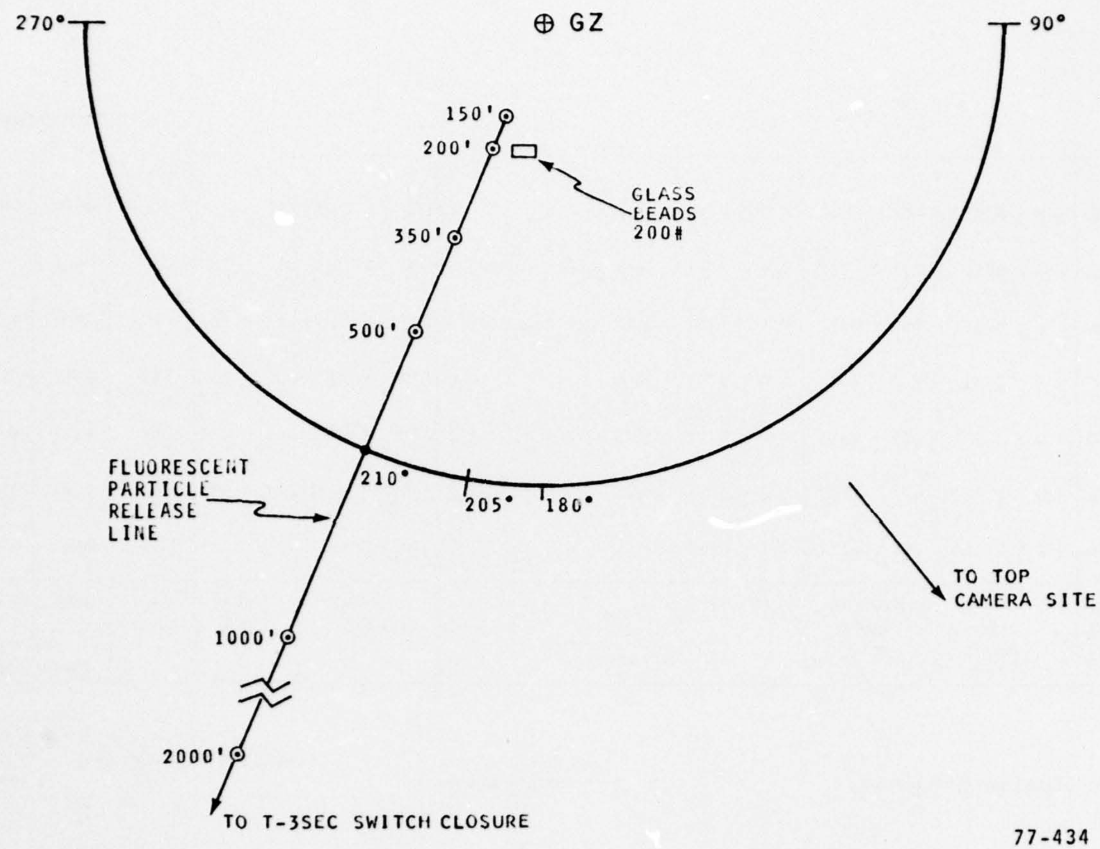

Figure 1. Middle Gust I - Location of glass beads and fluorescent particle (F.P.) releases.

wet cyclone jars (Appendix IV), the dust was transferred to small flat-bottomed glass vials, allowed to sediment and then to dry in the vial. When the bottoms of the vials were examined microscopically, it was found that the high specific gravity of (Zn, Cd)S particles had settled first. Particle counts (Table 2) of these vials revealed that all the F.P. was in the stem and none was in the main cloud, implying sweepup of air and fine particles (5 μ diameter) into the stem but no coupling between the main detonation cloud and the air that had been drawn into the stem.

Further analysis and discussion of the dust concentrations, size distribution, and specific gravity measurements for all the Middle Gust/Mixed Company tests are contained in Section 4.

3.2 MIDDLE GUST II

Middle Gust II was a 100-ton simulated air blast with an elevated R-2 configuration one charge radius above ground. The ground location was over wet sandy clay approximately 200 yards northeast of the Middle Gust I detonation. Several delays were encountered due to state approvals and weather. The test was conducted at 1:00 p.m. on 14 December 1971. Two instrumented aircraft were used to sample dust from the detonation.

A light snowfall the night before the test caused problems with the tracer experiments. Weather caused problems for the aircraft as they tried to locate the dust cloud after it became imbedded in the residual overcast.

3.2.1 Instrumentation and Experiments

The C-45 aircraft was instrumented with the following dust sampling/sensing equipment:

Table 2. Middle Gust I - Fluorescent particle counts.

Pass #	Location	Count
1	Main cloud	0
2	Main cloud	0
3	Stem	14
4	Stem	20
5	Stem	21
6	Stem	28
7	Stem	32

A background sample collected for 10 minutes after completion of the sampling passes revealed one (1) particle.

Wet Cyclone

Dry Filter

F. P. Drum Sampler

Integrating Nephelometer

Condensation Nuclei Monitor

TSI Mass Monitor

In addition temperature, altitude, indicated airspeed, and turbulence were recorded.

A second aircraft, the MRI Piper Aztec, was instrumented with the following equipment:

Wet Cyclone

Tape Sampler

F. P. Drum Sampler

Integrating Nephelometer

as well as the aircraft's normal complement of cloud physics instruments, including a continuous Formvar replicator, a foil impactor, and a portable instrument package to record temperature, indicated airspeed, altitude, relative humidity, and aircraft heading.

The replicator was designed to sample ice and water particles in the 2-20 μm diameter range and was used to detect any nucleation of water/ice on dust particles. Post-test examination of the tapes did not indicate the presence of condensed moisture on the dust particles, probably due to the thermal environment of the cloud which would promote evaporation rather than condensation.

The foil impactor, normally used for mapping in-cloud precipitation, replicates particles larger than 2 mm diameter by impressing an image in aluminum foil. The air burst nature of the detonation did not produce precipitation sized particles of a size that could be detected by the foil impactor.

Both aircraft performed a complete circle of the cloud at 3000-4500 feet above ground as the cloud rose to stabilization height. Each circle lasted about 1-1/2 minutes,starting at Z + 1:37(C-45) and Z + 2:17 (Aztec) in order to detect large particles cast out of the main cloud. No significant quantity of dust was detected.

At Z + 6:20, the Aztec penetrated the main cloud at 4250 feet and measured an average dust concentration of 1:15 $\times$ 10^{-8} gm/cm^3, or approximately 1/6 of the concentration resulting from the lower yield (20-ton), half-buried MG-I shot. Shortly thereafter, the C-45 entered at a lower altitude of 3950 feet and detected a slightly higher concentration of 1.59 $\times$ 10^{-8} gm/cm^3.

The Aztec continued to sample at higher altitudes than the C-45 until, at Z + 16:02, the Aztec attempted to make a top-to-bottom pass through the cloud. The C-45 continued to sample up to Z + 28:09 minutes; however, during all passes, it was difficult to position the aircraft for centerline penetrations due to the incorporation of the dust cloud in the nearly continuous stratus deck.

Aircraft data and computed dust concentrations are summarized in Tables 3 and 4.

Ground tracer experiments included two fields of glass beads, a trench filled with glass bubbles, and two units of fluorescent particle dispensers (Figure 2).

The first line of four F. P. dispensers was located in a 60° arc at 120 feet from GZ. The second line was at 300 feet and consisted of eight dispensers. Each dispenser was charged with 84 grams of F. P. Firing occurred three seconds before detonation. Ground photography and subsequent examination of the dispensers indicated that only

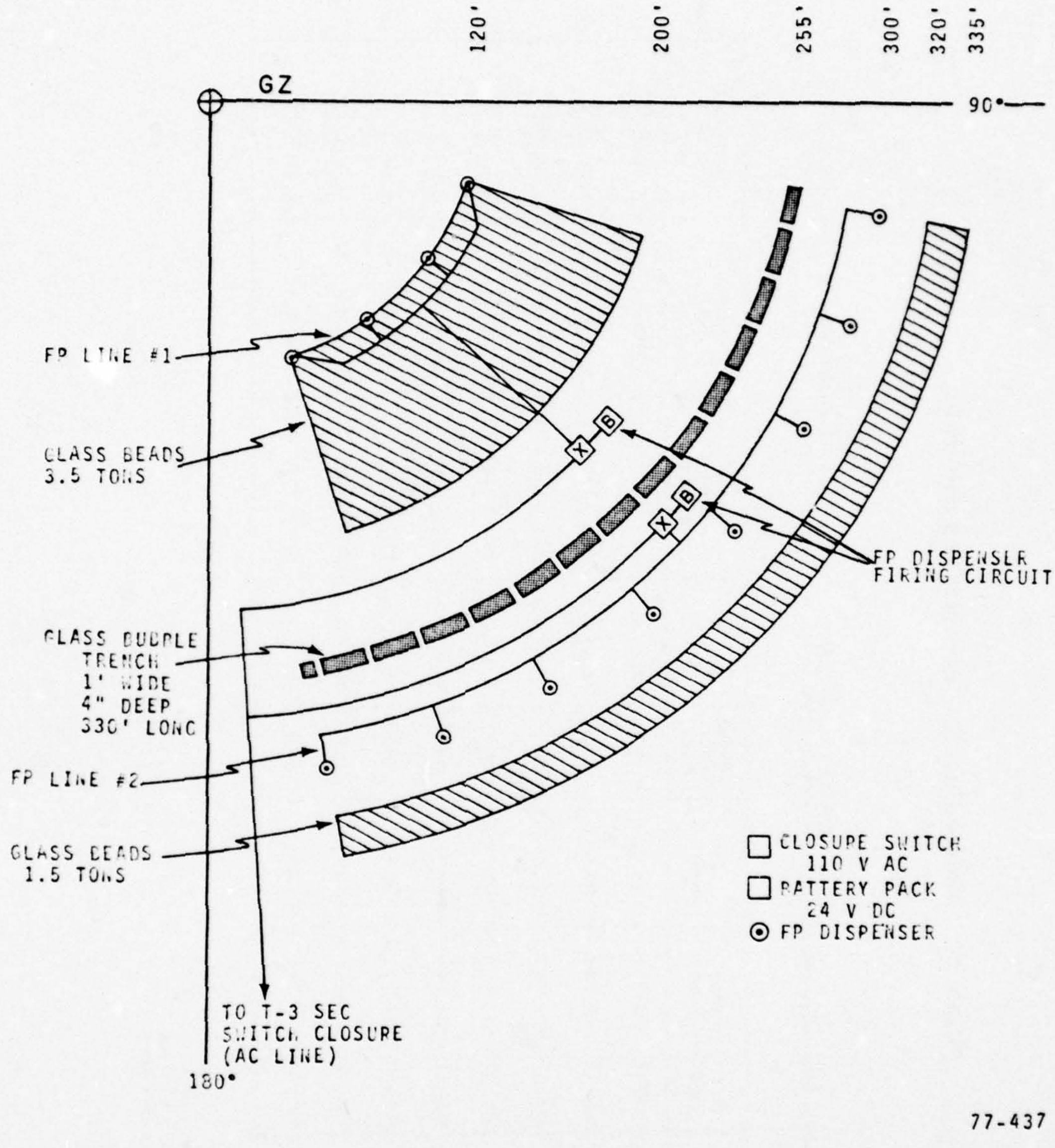

Figure 2. Middle Gust II - Location of glass beads, glass bubbles and fluorescent particle (F.P.) dispensers.

Table 3. Middle Gust II - Aircraft and dust data.

Event - MG II
Configuration - R-2 (Elevated Sphere [one charge radius])
Yield - 100 tons

Sampling Aircraft C-45
14 December 1971

Prevailing Wind Direction - SW

Pass No.	Location	Alt. Above Gz (ft)		Hdg. (deg)	TAS (mph)	Entry (min:sec)	Exit (min:sec)	Criteria* Entry/Exit	Δt (secs)	Cloud Width (meters)	Total Dust (mg)	Dust Conc. (x 10^{-8} gm/cc)	Rmks.	Sized	Dens. Dist.
		Entry	Exit												
1	Outside Cloud	3000	3550	Circle	159 ± 10	1:37.0 ± 0.1	2:18.9 ± 0.1	N/V	41.9 ± 0.2	NA	1.3 ± 0.5	$0.030^{+0.028}_{-0.017}$	(1)	No	No
2	Main Cloud	3950	4100	150	168 ± 11	6:27.2 ± 0.1	7:00.0 ± 0.1	N/V	32.8 ± 0.2	2463 ± 176	79.9 ± 0.5	$1.59^{+0.39}_{-0.28}$	(2)	No	No
3	Main Cloud	4000	3850	360	148 ± 10	9:34.7 ± 0.1	10:16.5 ± 0.1	N/V	41.8 ± 0.2	2765 ± 200	58.2 ± 0.5	$0.843^{+0.208}_{-0.151}$		No	No
4	Main Cloud	4400	4550	125	176 ± 11	13:11.2 ± 0.1	13:46.0 ± 0.2	N/V	34.8 ± 0.3	2738 ± 195	66.0 ± 0.5	$0.966^{+0.236}_{-0.171}$		No	No
5	Main Cloud	4400	4500	40	176 ± 11	17:19.9 ± 0.1	18:04.3 ± 0.1	N/V	44.4 ± 0.2	3493 ± 234	42.6 ± 0.5	$0.488^{+0.120}_{-0.086}$		No	No
6	Main Cloud	4250	4350	60	189 ± 12	20:53.2 ± 0.2	21:37.0 ± 0.1	N/V	43.8 ± 0.2	3700 ± 252	29.4 ± 0.5	$0.348^{+0.087}_{-0.064}$	(3)	No	No
7	Main Cloud	4450	4350	360	190 ± 12	23:37.3 ± 0.1	24:11.1 ± 0.1	N/N	33.8 ± 0.2	2871 ± 198	15.5 ± 0.5	$0.216^{+0.058}_{-0.043}$		No	No
8	Main Cloud	3850	3900	90	188 ± 12	28:09.5 ± 0.1	28:37.0 ± 0.2	N/N	27.5 ± 0.3	2311 ± 173	2.8 ± 0.5	$0.049^{+0.026}_{-0.017}$		No	No

* N = Nephelometer; V = Visual

(1) Cyclone valve closed 17.7 seconds before exit.
(2) Cyclone valve opened 6.0 seconds after entry.
(3) Cyclone valve opened 3.7 seconds after entry.
NA - Not Applicable

Table 4. Middle Gust II - Aircraft and dust data.

Event - MG II
Configuration - R-2 (Elevated Sphere [one charge radius])
Yield - 100 tons

Sampling Aircraft - Aztec
14 December 1971

Prevailing Wind Direction - SW

Pass No.	Location	Alt. Above Gz (ft)		Hdg. (deg)	TAS (mph)	Entry (min:sec)	Exit (min:sec)	Criteria* Entry/ Exit	Δt (secs)	Cloud Width (meters)	Total Dust (mg)	Dust Conc. (x 10^{-8} gm/cc)	Rmks.	Sized	Dens. Dist.
		Entry	Exit												
1	Outside Cloud	3650	4850	Circle	128 ± 5	2:16.9 ± 0.2	4:02.3 ± 0.2	N/N	105.4 ± 0.4	NA	3.6 ± 0.5	$0.040^{+0.017}_{-0.011}$	(1)	No	No
2	Main Cloud	4250	4300	155	140 ± 6	6:20.7 ± 0.1	7:00.7 ± 0.2	N/N	40.0 ± 0.3	2503 ± 126	71.9 ± 0.5	$1.15^{+0.257}_{-0.179}$		No	No
3	Main Cloud	4250	4300	340	145 ± 6	9:34.0 ± 0.1	10:20.0 ± 0.1	N/N	46.0 ± 0.2	2981 ± 136	72.3 ± 0.5	$0.971^{+0.212}_{-0.146}$		No	No
4	Top Main Cloud	5300	5200	165	151 ± 6	12:28.9 ± 0.2	12:56.3 ± 0.1	N/N	27.4 ± 0.3	1849 ± 94	14.2 ± 0.5	$0.308^{+0.077}_{-0.057}$		No	No
5	Top to Bottom Main Cloud	4850	4600	35	125 ± 5	16:02.4 ± 0.1	16:18.5 ± 0.1	N/N	16.1 ± 0.2	900 ± 47	28.4 ± 0.5	$1.26^{+0.298}_{-0.212}$		No	No

* N = Nephelometer; V = Visual

(1) Cyclone valve closed 43 seconds before exit.

NA - Not Applicable

6 of the 12 units fired properly; however, the total release of 500 grams was sufficient to conduct a tracer experiment.

The first glass bead field was composed of 3.5 tons of beads spread between 120 feet and 200 feet from GZ. These particles were in the range of 125-177 microns in diameter. The second field was at 320-335 feet and consisted of 1.5 tons of beads in the range of 44-88 microns. Dosages in both cases were determined by calculating probabilities of detecting 10 or more particles of either type in a given pass through the cloud.

The bubbles were located in a one-foot wide, four-inch deep trench at 225 feet from GZ.

As mentioned before, the soil particle simulant experiments were ruined by a light snowfall which covered the fields the prior evening. There was little evidence that the particles had moved under the snow.

3.2.2 Discussion

The dust concentrations reported in Tables 3 and 4 were computed based on the volume of air intercepted by the wet cyclone inlet during the time the sampling valves were open. In several cases, as noted in the footnotes, the valves were opened or closed while the aircraft was still inside the cloud. In these cases, the concentration is reported for only that portion of the cloud which was sampled.

During the first two passes for both aircraft, penetration was not made, and the indicated concentration simply represents a random background sample of the dust environment outside the visible edge of the cloud.

Due to the uncertainties regarding the portion of the cloud sampled, no size distributions or density determinations were made on the Middle Gust II samples.

The samples are available, and these analyses can be performed at a future date.

Small quantities of F.P. (1-4 particles per pass) were sampled by both aircraft in the main cloud. The absolute quantities were a factor of 10 less than appeared in the samples collected in the stem of the MG-I cloud. No passes were made through the stem of the MG-II cloud; thus, direct comparisons cannot be made. However, the presence of particles in the main cloud does support the thesis that circulation exists between the apron or sweep up zone and the toroid of the rising cloud.

Further discussion of the dust samples collected during MG-II is contained in Section 5.

3.3 MINE THROW I

3.3.1 General Conditions

On 15 December 1971, the day after the Middle Gust II test, the C-45 aircraft flew to the Nevada Test Range and sampled the dust cloud from Mine Throw I. Mine Throw I was a 100-ton, surface-coupled detonation of ANFO lining a previous nuclear crater. The Aztec aircraft did not participate, and no ground experiments were undertaken.

The weather was extremely clear, permitting accurate placement of the aircraft relative to the cloud prior to each penetration. In contrast to the Middle Gust I, Middle Gust II, and subsequent clouds in the MG-MC series, the Mine Throw cloud quickly formed a column with a thick, visible stem and an irregular or poorly developed main cloud.

A total of 12 passes was made through the cloud, starting at Z + 2:56.6 minutes and ending at Z + 39:13.0. These passes were grouped into four sets; the first three were in the main cloud; the second three were in the upper stem; the third three were in the lower stem; and the last three were back in the main cloud. Due to previous cratering at the site and associated mechanical attrition of the soil, the dust cloud lofted by the detonation had the highest loading of any cloud in the Middle Gust-Mine Throw-Mixed Company series. The first two passes encountered concentrations of 1 to 2 grams of dust per cubic meter compared to 0.01 gm/m^3 on Middle Gust II.

3.3.2 Instrumentation

The Middle Gust II complement of instrumentation on the C-45 was used on Mine Throw I; however, due to the absence of ground experiments, only the following instruments were operated:

Wet Cyclone
Dry Filter
Condensation Nuclei Monitor
Nephelometer

as well as the temperature, altitude, indicated airspeed, and turbulence sensors.

3.3.3 Discussion

Aircraft data and computed dust concentrations are summarized in Table 5. All entry times were determined by the nephelometer; however, due to the extremely high dust concentrations and the relatively slow clearing of the nephelometer, visual exit times were used.

The cloud expanded rapidly due to turbulence and elongated in the north-south direction under the influence of relatively high winds.

Table 5. Mine Throw I - Aircraft and dust data.

Event - MT I
Configuration - Surface Coupled
Yield - 100 tons

Sampling Aircraft - C-45
15 December 1971

Prevailing Wind Direction - S

Pass No.	Location	Alt. Above Gz (ft)		Hdg. (deg)	TAS (mph)	Entry (min:sec)	Exit (min:sec)	Criteria* Entry/Exit	Δ t (secs)	Cloud Width (meters)	Total Dust (mg)	Dust Conc. (x 10^{-8} gm/cc)	Rmks.	Sized	Dens. Dist.
		Entry	Exit												
1	Main Cloud	3750	3800	335	176 ± 14	2:56.6 ± 0.2	3:03.0 ± 0.2	N/V	6.4 ± 0.4	504 ± 72	2564.1 ± 0.5	204^{+62}_{-49}		No	No
2	Main Cloud	4400	4450	300	178 ± 14	5:57.9 ± 0.1	6:08.2 ± 0.1	N/V	10.3 ± 0.2	820 ± 80	2302.1 ± 0.5	113^{+30}_{-22}		No	No
3	Main Cloud	4500	4550	312	192 ± 15	9:03.9 ± 0.1	9:11.1 ± 0.1	N/V	7.2 ± 0.2	618 ± 65	680.4 ± 0.5	$44.1^{+12.0}_{-9.0}$		No	No
4	Upper Stem	2400	2250	330	185 ± 14	13:09.5 ± 0.1	13:33.4 ± 0.1	N/V	23.9 ± 0.2	1976 ± 166	986.5 ± 0.5	$20.0^{+5.0}_{-3.6}$		Yes	Yes
5	Upper Stem	2100	2100	337	184 ± 14	17:17.2 ± 0.1	17:48.8 ± 0.1	N/V	31.6 ± 0.2	2599 ± 214	554.7 ± 0.5	$8.55^{+2.13}_{-1.55}$		No	No
6	Upper Stem	2150	1750	360-330	184 ± 14	20:26.1 ± 0.1	21:27.5 ± 0.1	N/V	61.4 ± 0.2	5050 ± 401	306.9 ± 0.5	$2.43^{+0.60}_{-0.44}$		No	No
7	Lower Stem	1700	1650	130	183 ± 14	22:59.8 ± 0.1	23:35.8 ± 0.1	N/V	36.0 ± 0.2	2945 ± 242	304.1 ± 0.5	$4.14^{+1.03}_{-0.75}$		Yes	No
8	Lower Stem	1750	1700	320	183 ± 14	25:22.0 ± 0.1	26:11.3 ± 0.1	N/V	49.3 ± 0.2	4033 ± 325	267.0 ± 0.5	$2.65^{+0.66}_{-0.48}$		No	No
9	Lower Stem	1700	1750	350	196 ± 15	28:46.6 ± 0.2	29:43.2 ± 0.2	N/V	56.6 ± 0.4	4959 ± 415	243.4 ± 0.5	$1.97^{+0.49}_{-0.36}$		No	No
10	Main Cloud	3100	3200	105	174 ± 14	32:44.2 ± 0.2	33:18.8 ± 0.2	N/V	24.6 ± 0.4	1913 ± 185	218.6 ± 0.5	$4.58^{+1.21}_{-0.90}$		No	No
11	Main Cloud	3150	2950	340	187 ± 14	35:05.6 ± 0.2	35:48.6 ± 0.2	N/V	43.0 ± 0.4	3594 ± 303	111.9 ± 0.5	$1.25^{+0.32}_{-0.23}$		No	No
12	Main Cloud	2950	3150	65	200 ± 15	38:17.0 ± 0.2	39:13.0 ± 0.2	N/V	56.0 ± 0.4	5006 ± 411	127.2 ± 0.5	$1.02^{+0.26}_{-0.19}$		No	No

* N = Nephelometer; V = Visual.

As indicated earlier and seen in Table 5 (Column 10 -- Cloud Width), the dimensions of the stem, corrected for heading and the passage of time, were comparable to the main cloud, giving the cloud a columnar appearance. Two samples in the stem were sized and a comparison of these with samples from other tests on different soil media verified the high visibility of the stem due to fine particles.

The high concentration of dust in all samples from Mine Throw I provided a good statistical base for comparing the wet cyclone dust sampling technique with the dry filter. These data, as well as laboratory tests of both systems before and after the tests, lead to the conclusion that the wet cyclone technique was the better choice for sampling airborne dust.

Retention of particles due to wall effects and sedimentation in the filter holder was high, and the sampling rate in the filter system was less than the cyclone due to pressure drop across the filter. Measured collection efficiencies for the filter ranged from 81-98 percent as opposed to the more usable range of 93-97 percent for the cyclone.

The principal problem with the filter proved to be the high tare weight relative to the net weight of the sample collected. Originally, attempts were made to remove the sample and weigh it independently, but, due to the fact that the filter membrane served as both a barrier for the larger particles and a true filter or trap for the fines, quantitative recovery was impossible. The filter cartridge had to be weighed beforehand in the lab, sealed, used, and then reweighed back at the lab. Secondary contamination and the absorption/desorption of moisture due to changes in relative humidity made the system difficult to use. Although it was used once more on Middle Gust III, it was dropped in favor of the wet cyclone. All data on in-cloud dust concentrations were derived from the wet cyclone samples.

Further discussions of the dust sample measurements, size distributions, and density measurements made on the Mine Throw I samples are contained in Section 4.

3.4 MIDDLE GUST III

3.4.1 General Conditions

Middle Gust III was a 100-ton tangent sphere detonated on 13 April 1972 at a site approximately 200 yards ENE of the Middle Gust II site. The detonation occurred at 3:00 p.m., shortly after the passage of a frontal system. Scattered clouds did not interfere with the airborne sampling; however, surface winds gusting up to 35 knots moved the dust cloud to the northeast, causing rapid elongation and distortion. The fallout on the ground was confined to a narrow corridor under the track of the cloud. On occasion, the aircraft experienced moderate-to-severe turbulence while operating near the cloud and upon landing.

3.4.2 Instrumentation and Experiments

The C-45 was instrumented with the following samplers and sensors:

- Wet Cyclone
- Filter Sampler
- F. P. Drum Sampler
- Integrating Nephelometer
- Condensation Nuclei Counter
- Continuous Tape Sampler

In addition, temperature and altitude, indicated airspeed, and turbulence were recorded. For the first time, the primary data recording system was a Metrodata Data Logger which records in a format compatible with the MRI PDP-8 computer. A sample of the computer output is presented in Table 6. Stripchart records using a Honeywell Visicorder were collected simultaneously as backup to the Data Logger.

Penetration of the cloud was made at the earliest time possible, one minute and thirty two seconds (1:32) after detonation. This entry proved to be the earliest direct penetration of the main cloud during all the Middle Gust-Mixed Company tests. The Mixed Company III cloud was underflown at Z + 1:22 to pick up large particle fallout; however the actual visible cloud was not entered until 4:38.

At the time of the first pass through the Middle Gust III cloud, the cloud had developed two large lobes with clear air between them. The sample collected represents an integrated value of the two lobes plus the intervening clear air; thus the actual concentration was higher than the value reported under the column entitled, "Dust Conc." in Table 7.

The second pass, at Z + 2:38, occurred right at the base of the main cloud. Severe turbulence was encountered as the aircraft left the stem and entered the shear zone between the rapidly rising stem and the ambient air. Future plans to use light aircraft in this type of sampling should be cognizant of these risks.

The next seven passes were made in the stem down to an altitude of 2300 feet above ground level. The main cloud was reentered on Pass #10, and five additional samples were taken until operations ceased at Z + 30:09. Toward the end of the sampling, the cloud had been elongated into a ribbon of fine dust particles measuring 13,000 feet by 1300 feet.

Table 6. Middle Gust III - Sample data logger output - 13 April 1972.

LIN NEPH AVE= 0.81E-04 MAX= 1.12E-04 MIN= 0.46E-04
MASS AVE= 0.311E-02 MAX= 0.425E-02 MIN= 0.174E-02

PASS	TIME	LOG NEPH	IAS (MPH)	TURB	ALT (FT)	LIN NEPH (/M)	MASS (1E-8GMS/CC)	DSP (DEG)	TEMP (DEG C)	CNM
4	520.2	5.06	142.64	5.61	6709.	1.01E-04	0.386E-02	109.02	99.99	0.320E 02
4	521.2	5.14	143.21	5.66	6683.	1.08E-04	0.413E-02	108.72	99.99	0.200E 02
4	522.2	5.59	144.26	5.78	6698.	1.35E-04	0.513E-02	108.64	99.99	0.800E 01
4	523.2	6.87	143.11	6.08	6695.	1.54E-04	0.586E-02	110.36	99.99	0.440E 02
4	524.2	7.34	145.43	5.50	6710.	5.39E-04	0.204E-01	110.21	99.99	0.440E 02
4	525.2	8.86	144.13	4.57	6702.	16.71E-04	0.635E-01	110.58	99.99	0.400E 02
4	526.2	8.95	144.64	4.51	6731.	17.59E-04	0.668E-01	111.40	99.99	0.500E 02
4	527.2	9.14	142.79	4.22	6747.	21.13E-04	0.803E-01	112.22	99.99	0.200E 02
4	528.2	9.95	150.22	3.94	6787.	37.22E-04	0.141E 00	112.81	99.99	0.400E 02
4	529.2	9.74	148.63	4.56	6814.	33.04E-04	0.125E 00	113.93	99.99	0.380E 02
4	530.2	9.36	144.58	4.44	6811.	24.67E-04	0.937E-01	113.34	99.99	0.260E 02
4	531.2	9.24	142.20	5.04	6832.	22.36E-04	0.849E-01	113.93	99.99	0.160E 02
4	532.2	9.15	144.60	4.83	6851.	20.24E-04	0.769E-01	113.86	99.99	0.220E 02
4	533.2	8.17	143.62	4.86	6870.	10.16E-04	0.386E-01	114.38	99.99	0.420E 02
4	534.2	7.23	142.50	4.20	6821.	4.80E-04	0.182E-01	113.93	99.99	0.140E 02
4	535.2	7.14	143.73	4.27	6863.	4.83E-04	0.183E-01	114.45	99.99	0.360E 02
4	536.2	7.93	144.82	4.10	6851.	8.37E-04	0.318E-01	114.90	99.99	0.140E 02
4	537.2	9.00	142.31	3.62	6901.	18.27E-04	0.694E-01	115.27	99.99	0.160E 02
4	538.2	8.73	142.90	3.03	6908.	14.64E-04	0.556E-01	117.80	99.99	0.400E 02
4	539.2	7.16	140.32	3.01	6944.	4.68E-04	0.177E-01	119.00	99.99	0.380E 02
4	540.2	5.54	141.32	3.04	6930.	1.45E-04	0.553E-02	118.32	99.99	0.120E 02
4	541.2	4.73	138.77	2.86	6927.	0.87E-04	0.331E-02	119.22	99.99	0.240E 02

LIN NEPH AVE= 12.33E-04 MAX= 37.22E-04 MIN= 0.87E-04
MASS AVE= 0.468E-01 MAX= 0.141E 00 MIN= 0.331E-02

PASS	TIME	LOG NEPH	IAS (MPH)	TURB	ALT (FT)	LIN NEPH (/M)	MASS (1E-8GMS/CC)	DSP (DEG)	TEMP (DEG C)	CNM
0	542.2	4.29	138.51	2.87	6939.	0.61E-04	0.234E-02	118.62	99.99	0.200E 02
0	552.2	3.77	132.55	3.03	6986.	0.50E-04	0.191E-02	120.19	99.99	0.440E 02
0	6 2.2	3.40	130.75	3.93	7027.	0.63E-04	0.240E-02	121.53	99.99	0.900E 02
0	612.2	3.53	133.81	3.16	6960.	0.56E-04	0.215E-02	120.26	99.99	0.220E 02
0	622.2	4.06	144.80	2.45	6903.	0.34E-04	0.130E-02	120.26	99.99	0.600E 01

LIN NEPH AVE= 0.53E-04 MAX= 0.63E-04 MIN= 0.34E-04
MASS AVE= 0.202E-02 MAX= 0.240E-02 MIN= 0.130E-02

PASS	TIME	LOG NEPH	IAS (MPH)	TURB	ALT (FT)	LIN NEPH (/M)	MASS (1E-8GMS/CC)	DSP (DEG)	TEMP (DEG C)	CNM
5	624.2	4.26	146.14	2.94	6889.	0.41E-04	0.158E-02	120.63	99.99	0.380E 02
5	625.2	6.76	148.72	3.53	6892.	1.80E-04	0.687E-02	120.04	99.99	0.800E 01
5	626.2	8.08	148.54	3.59	6896.	9.27E-04	0.352E-01	120.63	99.99	0.300E 02
5	627.2	8.11	148.84	4.16	6887.	9.64E-04	0.366E-01	121.38	99.99	0.120E 02
5	628.2	7.99	146.30	4.05	6894.	7.87E-04	0.299E-01	121.15	99.99	0.120E 02
5	629.2	8.20	147.26	7.39	6903.	10.28E-04	0.390E-01	121.60	99.99	0.200E 02
5	630.2	8.68	144.53	6.67	6735.	14.72E-04	0.559E-01	122.27	99.99	0.360E 02
5	631.2	9.28	145.60	5.44	6716.	23.02E-04	0.874E-01	122.64	99.99	0.400E 01
5	632.2	9.13	144.56	5.28	6710.	20.41E-04	0.775E-01	123.09	99.99	0.200E 02
5	633.2	8.63	145.98	4.75	6736.	13.88E-04	0.527E-01	123.46	99.99	-0.200E 01
5	634.2	7.94	141.63	4.63	6730.	8.16E-04	0.310E-01	124.28	99.99	-0.220E 02
5	635.2	6.54	138.21	3.95	6755.	2.89E-04	0.109E-01	123.41	99.99	-0.400E 01
5	636.2	5.53	139.24	4.40	6773.	1.36E-04	0.516E-02	124.13	99.99	0.100E 02
5	637.2	5.05	143.64	4.72	6762.	1.11E-04	0.422E-02	124.65	99.99	0.200E 01

LIN NEPH AVE= 8.91E-04 MAX= 23.02E-04 MIN= 0.41E-04

Table 7. Middle Gust III - Aircraft and dust data.

Event - MGIII
Configuration - Tangent Sphere
Yield - 100 tons

Sampling Aircraft C-45
13 April 1972

Prevailing Wind Direction - WSW

Pass No.	Location	Alt. Above Gz (ft)		Hdg. (deg)	TAS (mph)	Entry (min:sec)	Exit (min:sec)	Criteria* Entry/Exit	Δ t (secs)	Cloud Width (meters)	Total Dust (mg)	Dust Conc. (x 10^{-8} gm/cc)	Rmks.	Sized	Dens. Dist.
		Entry	Exit												
1	Center Main Cloud	3400	3500	10	141 ± 10	1:32.0±0.1	1:38.7±0.1	V/V	6.7±0.2	422 ± 43	478.5 ± 0.5	$45.4^{+12.154}_{-9.068}$		Yes	Yes
2	Just Below Base of Cloud	3050	3400	350	161 ± 10	2:38.4±0.1	2:48.1±0.1	V/V	9.7±0.2	698 ± 58	205.7 ± 0.5	$24.4^{+6.652}_{-4.995}$	(1)	Yes	Yes
3	Stem Midway Between Gd. & Cloud	2350	2300	130	142 ± 10	4:13.6±0.2	4:34.4±0.1	N/N	20.8±0.3	1320 ± 112	219.9 ± 0.5	$9.01^{+2.326}_{-1.713}$	(2)	Yes	Yes
4	" " "	2300	2500	270	157 ± 10	5:22.0±0.1	5:40.7±0.1	N/N	18.7±0.2	1312 ± 98	NA	NA		NA	NA
5	" " "	2500	2350	40	159 ± 10	6:24.4±0.2	6:34.9±0.1	V/V	10.5±0.3	746 ± 68	120.1 ± 0.5	$13.8^{+4.065}_{-3.125}$	(3)	Yes	Yes
6	Stem, 1000 ft above #5	3200	3200	150	145 ± 10	7:37.6±0.2	7:59.6±0.2	V/N	22.0±0.4	1426 ± 124	72.9 ± 0.5	$2.05^{+0.532}_{-0.393}$		Yes	No
7	Stem, 1500 ft above #6	4250	4800	270	148 ± 10	9:04.6±0.1	9:35.5±0.2	N/N	30.9±0.3	2044 ± 158	96.7 ± 0.5	$1.89^{+0.471}_{-0.342}$		Yes	No
8	Stem, 1000 ft above #7	5550	6200	350	170 ± 10	10:48.4±0.1	11:20.3±0.2	N/N	31.9±0.3	2424 ± 165	49.1 ± 0.5	$0.811^{+0.198}_{-0.143}$		Yes	No
9	Stem, Near Cloud Base	7450	7900	150	151 ± 10	13:34.0±0.1	14:16.8±0.2	N/N	42.8±0.3	2889 ± 212	76.9 ± 0.5	$1.07^{+0.262}_{-0.189}$		Yes	No
10	Cloud Base	8150	8300	320	162 ± 11	14:42.8±0.1	15:30.7±0.1	N/V	47.9±0.2	3469 ± 250	86.8 ± 0.5	$1.00^{+0.244}_{-0.176}$		Yes	No
11	Main Cloud	9100	9200	50	169 ± 11	17:03.8±0.1	18:53.0±0.2	N/N	109.2±0.3	8249 ± 560	78.5 ± 0.5	$0.381^{+0.092}_{-0.066}$		No	No
12	Main Cloud	9150	9100	190	178 ± 12	20:27.3±0.1	20:44.2±0.2	N/N	16.9±0.3	1345 ± 115	10.1 ± 0.5	$0.301^{+0.090}_{-0.070}$		No	No
13	Main Cloud	8900	8850	50	172 ± 11	23:53.4±0.2	26:42.2±0.2	N/V	168.8±0.4	12978± 861	44.3 ± 0.5	$0.137^{+0.033}_{-0.024}$		No	No
14	Main Cloud	8350	8400	210	184 ± 12	28:56.9±0.1	30:09.2±0.1	N/N	72.3±0.2	5947± 404	9.8 ± 0.5	$0.066^{+0.019}_{-0.014}$		No	No

* V = Visual; N = Nephelometer.

(1) Cyclone valve opened 5 secs. after entry.
(2) Cyclone valve opened 5.4 secs. after entry.
(3) Cyclone valve opened 5.6 secs. after entry.

In Figure 3, the envelope of the visible cloud is defined by the heavy lines, the aircraft passes by diamonds, and the theoretical trajectories of the largest particles by the lighter lines. The largest particles sampled during Passes #5 and #6 were about 900 μm in diameter or comparable to the expected 1000 μm diameter "largest particle" indicated in Figure 3. Earlier passes below the cloud indicated no particles larger than 1230 μm in diameter.

The fallout at ground level reflected the deficiency of particles larger than 1-2 mm in diameter. Due to the high winds on the day of the shot, the cloud moved off rapidly to the northeast along the 60-degree radial leaving a swath of fallout on the ground. Except for the heavy ejecta blanket near ground zero, the close-in dust fall was minimal out to 3000 feet. Beyond 3000 feet, in the path of the cloud, the concentration increased again from 0.28 to 1.45 g/m^2 (Figure 4). With the exception of a 4.5 mm diameter particle collected at 5000 ft, the largest particles deposited at ground level were measured at about 1.7 mm (Figure 5). Analysis of the horizontal transport at the cloud, the population of large particles in the cloud, and arrival times at the ground indicate that these particles were derived from the stem of the cloud.

Ground experiments were limited to two F.P. releases at 120 feet and 210 feet on the 210-degree radial and an array of fallout collection pans located on successive 30-degree radials (except 150 degrees and 210 degrees) at distances of 1000, 2000, 3000, 5000, and 8000 feet from GZ (Figure 6). Due to previous problems with the glass bead-glass bubble fields, these experiments were discontinued.

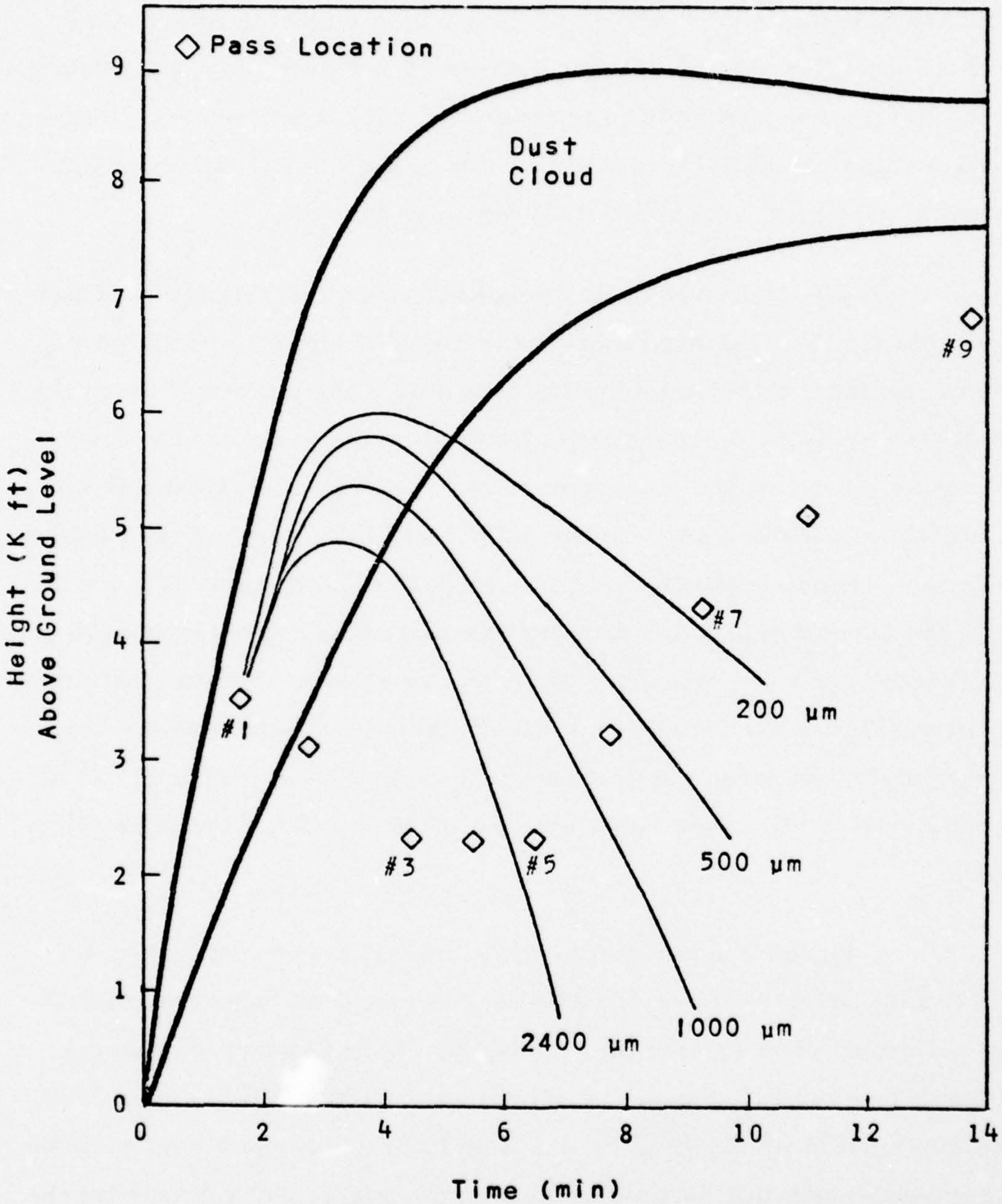

Figure 3. Middle Gust III - Dust cloud development. Aircraft sampling passes are indicated by diamonds. Theoretical largest particle trajectories are shown.

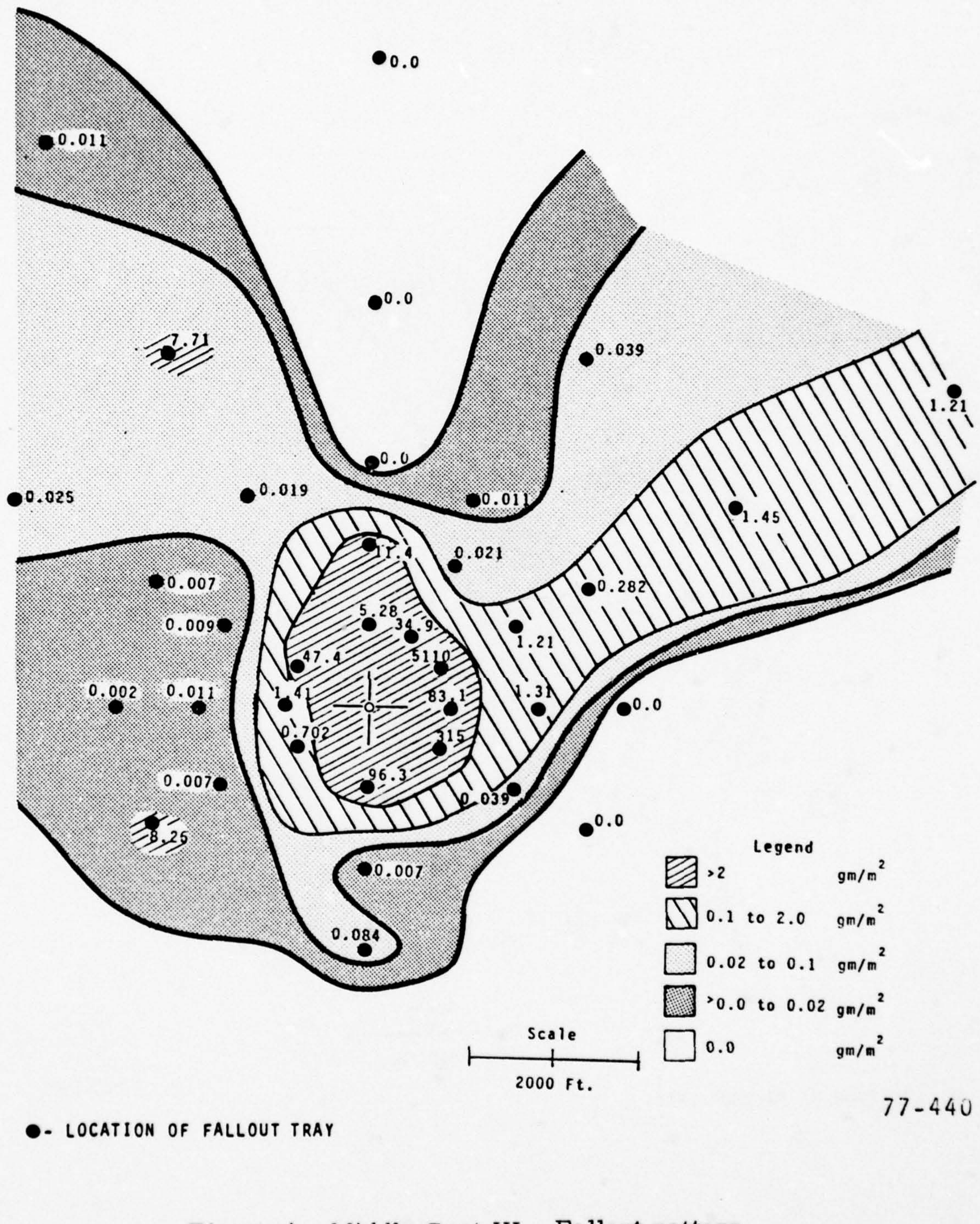

Figure 4. Middle Gust III - Fallout pattern.

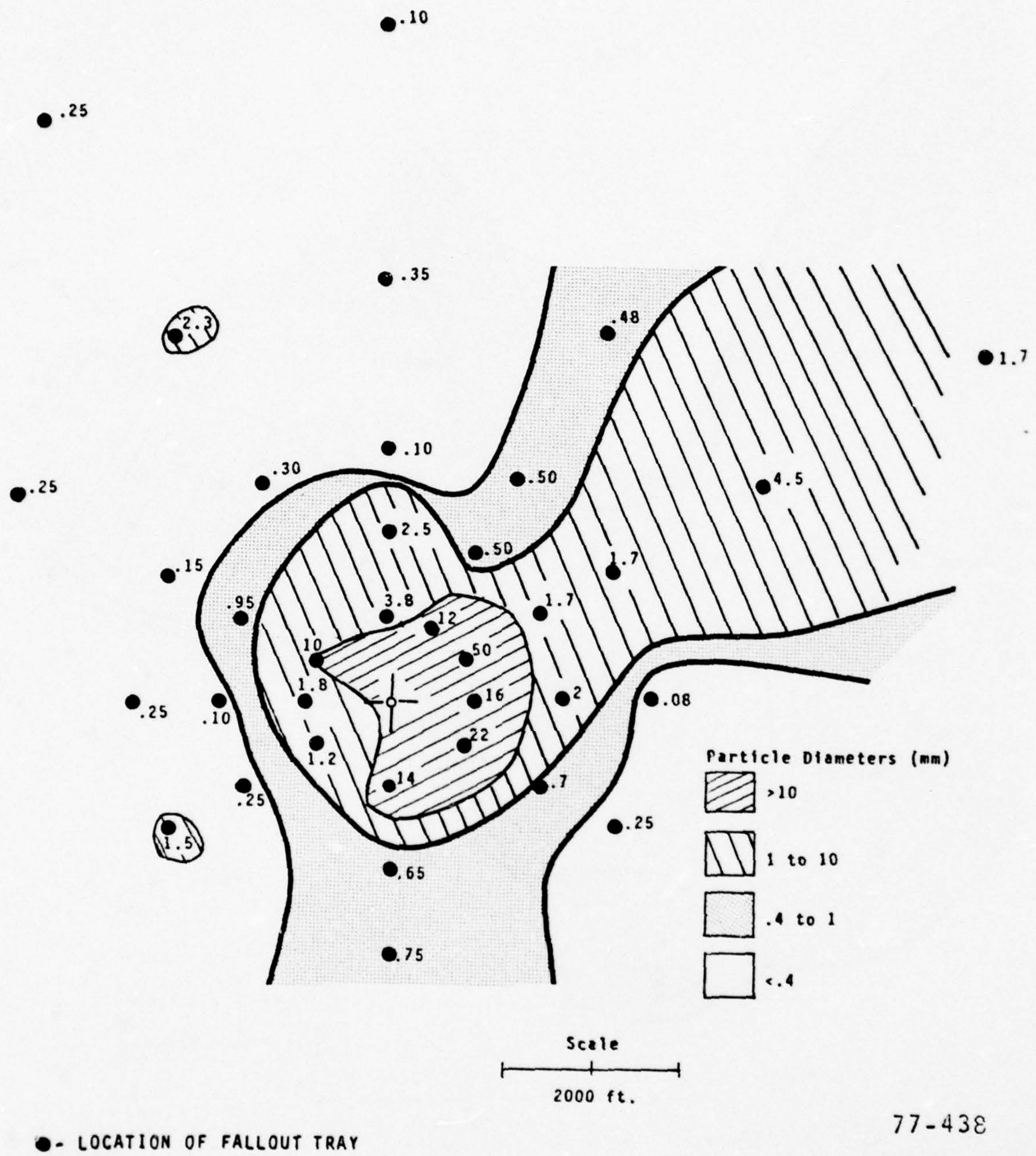

Figure 5. Middle Gust III - Largest fallout particles.

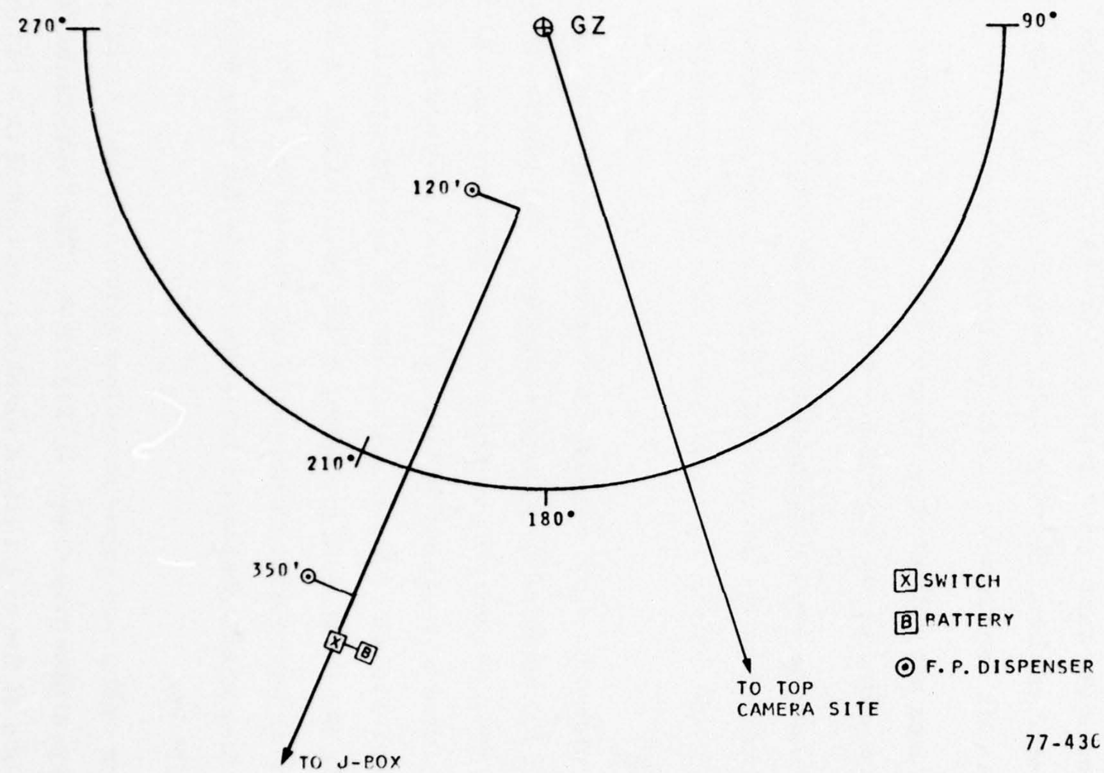

Figure 6. Middle Gust III - Location of fluorescent particle (F.P.) dispensers.

3.4.3 Discussion

The dust concentrations reported in Table 7 were based on samples collected by the wet cyclone, corrected for air sampling rate and the variances in the point when the cyclone values were opened. Each value represents the dust concentration of the part of the cloud sampled and, as noted earlier, the first value may be low due to an open pocket of clear air encountered inside the top of the cloud.

A sample was not collected on Pass #4 due to the disorder inside the aircraft created by the turbulence encountered on Pass #2.

Size distributions were determined for all the samples through Pass #10, thus documenting the early cloud, the stem, and a portion of the late cloud. Particle density as a function of size was determined on Samples 1, 2, 3, and 5.

The fluorescent particle releases occurred on schedule, at T minus 3 seconds as documented by ground cameras. The plumes moved approximately 120 feet, converging slightly toward ground zero. At the time of detonation, they were about 90 feet and 320 feet respectively from GZ on the 180-degree radial. This condition should have favored incorporation of the F.P. in the stem, and possibly, in the main cloud. A subsequent search of the airborne dust samples did not reveal any F.P., indicating that the surface winds displaced the stem at a faster rate than the F.P. could be swept up.

The fallout collection experiment was extremely successful as indicated by the deposition map drawn in Figure 4. The immediate fallout from one of the lobes of the cloud laid a blanket of material in a northwesterly direction while the main cloud moved rapidly to the northeast. In addition to the measurement of fallout density, each sample was searched for the "largest particle." The pan locations and the largest particles found are listed in Table 8. The map in Figure 5 shows the location of each particle relative to ground zero.

Table 8. Middle Gust III - Largest fallout Particles - 13 April 1972

Sample Location Bearing	Distance (ft.)	Largest Particle Diameter (mm)
0°	1000	3.8
	2000	2.5
	3000	0.10
	5000	0.35
	8000	0.10
30°	1000	12
	2000	0.50
	3000	0.50
	5000	0.48
60°	1000	50
	2000	1.7
	3000	1.7
	5000	4.5
	8000	1.7
90°	1000	16
	2000	2
	3000	0.08
120°	1000	22
	2000	0.70
	3000	0.25
180°	1000	14
	2000	0.65
	3000	0.75
240°	1000	1.2
	2000	0.25
	3000	1.5
270°	1000	1.8
	2000	0.1
	3000	0.25
300°	1000	10
	2000	0.95
	3000	0.15
	5000	0.25
330°	3000	0.30
	5000	2.3
	8000	0.25

The airborne dust samples and the fallout collection are discussed further in Section 4.

3.5 MIXED COMPANY I

3.5.1 General Conditions

On 1 June 1972, Meteorology Research, Inc., sampled the dust cloud from a small 20-ton half-buried (R=0) TNT detonation over sandstone beds at the Mixed Company site, southwest of Grant Junction, Colorado. This test was one of several pre-Mixed Company III calibration shots and did not involve the usual array of ground experiments. The MRI/EPA C-45 flew 16 penetrations of the stem and ground cloud.

Weather conditions were ideal with clear skies and moderate winds. Detonation occurred at 10:50 a.m., and the cloud rose rapidly to a stabilization level at approximately 5500 feet above ground level (12,000 feet above sea level).

3.5.2 Instrumentation and Experiments

The C-45 carried a minimum instrument package limited to the following samplers and sensors:

- Wet Cyclone
- Integrating Nephelometer
- Condensation Nuclei Counter
- Continuous Tape Sampler

as well as recording sensors for turbulence, indicated airspeed, temperature, and altitude.

The aircraft was positioned at an altitude of 3200 AGZ in anticipation that the cloud would rise slowly to an altitude above ground similar to the small 20-ton Middle Gust I cloud; however, lower atmospheric pressure and a well-contained fireball enabled the boule to rise very rapidly. In less than two minutes, the cloud was above the aircraft, and the first pass at Z + 1:57.7 had to be made under the cap cloud and outside the stem. Although flown in apparently clear air, trails of fallout from the cap could be seen. A dust concentration of $65.5 \begin{smallmatrix} +19.9 \\ -15.5 \end{smallmatrix} \times 10^{-8}$ gm/cm^3 was measured.

The cloud formed a perfect toroidal ring at an altitude of 12,000 feet which persisted for approximately ten minutes after the cloud had stabilized.

Attempts to reach the ring were abandoned when it was realized that excessive time would be consumed outside the cloud maneuvering for altitude gain. All measurements were restricted to the stem and ground cloud.

3.5.3 Discussion

The dust data reported in Table 9 were all determined from the wet cyclone samples. As indicated earlier, a relative high concentration was measured under the toroidal cap cloud but outside any portion of the visible cloud. This high mass was evidenced by the presence of particles 1.3 mm in diameter as opposed to particles no larger than 600 micons in the stem.

Three of the samples were sized, including the first one under the cap, the second in the stem, and the eleventh in the stem and ground cloud. Particle densities were measured for the first two samples collected.

Additional discussion of the dust samples is contained in Section 4.

Table 9. Mixed Company I - Aircraft and dust data.

Event - MC I
Configuration - R-0 (Half-buried Sphere)
Yield - 20 tons

Sampling Aircraft - C-45
1 June 1972

Prevailing Wind Direction - NNE

Pass No.	Location	Alt. Above Gz (ft) Entry	Alt. Above Gz (ft) Exit	Hdg. (deg)	TAS (mph)	Entry (min:sec)	Exit (min:sec)	Criteria* Entry/Exit	Δ t (secs)	Cloud Width (meters)	Total Dust (mg)	Dust Conc. (x 10^{-8} gm/cc)	Rmks.	Sized	Dens. Dist.
1	Under Cap Outside Stem	3250	3300	190	149 ± 13	1:51.7 ± 0.1	1:55.7 ± 0.1	N/V	4.0 ± 0.2	266 ± 37	436.0 ± 0.5	$65.5^{+19.9}_{-15.5}$		Yes	Yes
2	Stem	3750	3950	300	152 ± 13	3:20.1 ± 0.1	3:27.1 ± 0.1	N/V	7.0 ± 0.2	476 ± 54	290.8 ± 0.5	$24.5^{+6.9}_{-5.2}$		Yes	Yes
3	Stem	4100	4000	60	172 ± 14	4:24.0 ± 0.1	4:27.8 ± 0.1	N/V	3.8 ± 0.2	292 ± 39	68.2 ± 0.5	$9.35^{+2.87}_{-2.24}$		No	No
4	Stem	4150	4150	170	175 ± 14	5:29.2 ± 0.1	5:39.1 ± 0.1	N/V	9.9 ± 0.2	774 ± 78	108.0 ± 0.5	$5.59^{+1.51}_{-1.13}$		No	No
5	Stem	4200	4200	300	188 ± 15	6:39.7 ± 0.1	6:42.8 ± 0.1	N/V	3.1 ± 0.2	261 ± 38	132.8 ± 0.5	$20.4^{+6.4}_{-5.0}$		No	No
6	Stem	3550	3600	50	189 ± 15	7:52.4 ± 0.1	8:01.7 ± 0.1	N/V	9.3 ± 0.2	786 ± 79	358.0 ± 0.5	$18.2^{+4.9}_{-3.7}$		No	No
7	Stem	3200	3250	165	181 ± 14	8:55.5 ± 0.1	9:06.8 ± 0.1	N/V	11.3 ± 0.2	914 ± 87	258.3 ± 0.5	$11.3^{+3.0}_{-2.2}$		No	No
8	Stem	3500	3550	280	150 ± 13	9:58.9 ± 0.1	10:18.4 ± 0.1	N/V	19.5 ± 0.2	1307 ± 127	285.4 ± 0.5	$7.92^{+2.09}_{-1.56}$		No	No
9	Stem	3600	3650	55	164 ± 14	11:30.2 ± 0.1	11:39.7 ± 0.1	N/V	9.5 ± 0.2	696 ± 74	133.0 ± 0.5	$7.65^{+2.11}_{-1.59}$		No	No
10	Stem	3550	3500	180	167 ± 14	12:55.3 ± 0.1	13:06.3 ± 0.1	N/V	11.0 ± 0.2	821 ± 84	135.0 ± 0.5	$6.59^{+1.79}_{-1.34}$		No	No
11	Stem/Ground Cloud	2300	2400	300	166 ± 14	14:06.2 ± 0.1	14:25.6 ± 0.1	N/V	19.4 ± 0.2	1440 ± 136	151.0 ± 0.5	$4.20^{+1.11}_{-0.82}$		Yes	No
12	Ground Cloud	1350	1200	70	156 ± 13	15:35.1 ± 0.1	15:51.4 ± 0.1	N/V	16.3 ± 0.2	1137 ± 109	50.1 ± 0.5	$1.77^{+0.48}_{-0.36}$		No	No
13	Ground Cloud	1500	1750	140	142 ± 13	16:39.3 ± 0.1	17:25.4 ± 0.1	N/V	46.1 ± 0.2	2926 ± 281	106.0 ± 0.5	$1.45^{+0.39}_{-0.29}$		No	No
14	Stem/Ground Cloud	2750	3150	270	141 ± 13	19:06.6 ± 0.1	19:38.1 ± 0.1	N/V	31.5 ± 0.2	1985 ± 196	79.1 ± 0.5	$1.60^{+0.43}_{-0.32}$		No	No
15	Stem	4250	4450	35	139 ± 13	21:33.2 ± 0.1	21:55.1 ± 0.1	N/V	21.9 ± 0.2	1361 ± 140	40.7 ± 0.5	$1.20^{+0.34}_{-0.26}$		No	No
16	Stem	4300	4250	150	170 ± 14	23:13.4 ± 0.1	23:39.1 ± 0.1	N/V	25.7 ± 0.2	1953 ± 176	79.2 ± 0.5	$1.62^{+0.43}_{-0.32}$		No	No

* N = Nephelometer; V = Visual.

3.6 MIDDLE GUST IV

3.6.1 General Conditions

Middle Gust IV was a 100-ton tangent sphere detonated at 1:00 p.m., on 22 June 1972 at a site approximately five miles northeast of the Middle Gust III site outside Crowley, Colorado. The test was conducted over a dry zone of the same sandy clay present at the MG-III test.

The weather was excellent during the preparation phase and on the test date and presented no interference with either the ground experiments or the aircraft operation. A mild wind moved the dust in a general northerly direction without creating excessive distortion of the cloud.

3.6.2 Instrumentation and Experiments

The C-45 aircraft was equipped with the following instruments and sensors:

- Wet Cyclone
- Dry Cyclone
- F.P. Drum Sampler
- Integrating Nephelometer
- Condensation Nuclei Counter
- Continuous Tape Sampler

as well as recording sensors for temperature, altitude, indicated airspeed, and turbulence.

The dry cyclone replaced the filter sampler as an alternative method of sampling large quantities of dust particles without going through a washdown or wet phase. Tests of the dry cyclone versus the wet cyclone (Appendix IV-3) indicated that collection efficiency for small particles was degraded when the wet wall was eliminated. Typically, the dry cyclone collected 5-7 times as much dust per pass, even with collection efficiency and reentrainment losses, thus improving the probability of capturing a more statistically representative sample of the large particles. Samples from the dry cyclone were not analyzed to determine in-cloud dust concentration but were saved for future large particle identification.

A total of 18 passes were made through various segments of the main cloud and the stem (Table 10). This set of data represents the most systematic sampling of a total dust cloud system during the MG-MC series. The top, middle, and base of the main cloud, various portions of the stem from near ground (650 feet) to cloud base (4200 feet), and the area under the cap of the main cloud were sampled. Due to relatively low winds, the cloud maintained its form and permitted good definition of the location of the sampling points. Both the stem and the main cloud were sampled at two different times during the total period of 48 minutes.

The dust concentrations measured at comparable locations and times in the cloud were approximately two to four times less than the concentrations measured in the Middle Gust III cloud. The yield, configuration, and soil type were similar for Middle Gust III and IV except for the moisture content of the soil. It appears that water in the ground, as it is converted to steam by the fireball, controls the quantity of dust lofted by this type of explosion.

Ground experiments included a fallout collection network, three releases of fluorescent particles, and two releases of glass beads. Time-lapse photographs were taken from the technical observation post (TOP) and from a site 8000 feet WSW of ground zero.

Table 10. Middle Gust IV - Aircraft and dust data.

Event - Middle Gust IV
Configuration - Tangent Sphere
Yield - 100 tons

Sampling Aircraft C-45
22 June 1972

Prevailing Wind Direction - S

Pass No.	Location	Alt. Above Gz (ft)		Hdg. (deg)	TAS (mph)	Entry (min:sec)	Exit (min:sec)	Criteria* Entry/Exit	Δt (secs)	Cloud Width (meters)	Total Dust (mg)	Dust Conc. (x 10^{-8} gm/cc)	Rmks.	Sized	Dens. Dist.
		Entry	Exit												
1	Top of Cloud	4200	4250	230	167 ± 9	2:09.5±0.1	2:26.3±0.1	N/V	16.8±0.2	1254 ± 83	384.9±0.5	$12.3^{+2.9}_{-2.0}$		No	No
2	Main Cloud	4500	4650	0	156 ± 8	3:46.6±0.1	4:09.0±0.1	N/V	22.4±0.2	1562 ± 94	362.6±0.5	$9.3^{+2.1}_{-1.5}$		Yes	Yes
3	Base of Cloud	4400	4350	20	184 ± 9	5:44.4±0.1	6:05.0±0.5	N/V	20.6±0.6	1694 ± 132	166.1±0.5	$3.9^{+1.0}_{-0.7}$		No	No
4	Stem	3700	3750	130	169 ± 9	7:19.7±0.1	7:50.6±0.1	V/V	30.9±0.2	2334 ± 139	26.0±0.5	$0.446^{+0.109}_{-0.079}$		Yes	Yes
5	Stem	2700	2800	310	166 ± 9	9:25.2±0.1	9:42.9±0.1	N/V	17.7±0.2	1313 ± 86	15.0±0.5	$0.468^{+0.124}_{-0.092}$	(1)	No	No
6	Under Cloud	2800	2850	95	153 ± 8	10:56.3±0.1	11:44.3±0.1	V/V	48.0±0.2	3283 ± 185	24.8±0.5	$0.303^{+0.073}_{-0.053}$		No	No
7	Base of Cloud	3700	3700	230	150 ± 8	13:48.6±0.1	14:25.6±0.1	N/V	37.0±0.2	2481 ± 146	64.3±0.5	$1.04^{+0.24}_{-0.17}$	(2)	No	No
8	Main Cloud	5150	5350	10	143 ± 8	16:36.3±0.1	17:12.5±0.1	N/V	36.2±0.2	2314 ± 142	64.2±0.5	$1.11^{+0.26}_{-0.19}$		No	No
9	Main Cloud	5150	5200	140	165 ± 9	18:52.2±0.1	19:16.0±0.5	N/V	23.8±0.6	1755 ± 140	28.6±0.5	$0.773^{+0.207}_{-0.154}$	(3)	No	No
10	Main Cloud	4950	4950	255	163 ± 9	20:34.0±0.5	21:36.0±0.1	N/V	62.0±0.6	4517 ± 293	37.0±0.5	$0.328^{+0.080}_{-0.053}$		No	No
11	Main Cloud	5100	5150	15	139 ± 8	23:49.8±0.1	24:32.8±0.1	N/V	43.0±0.2	2672 ± 166	54.4±0.5	$0.833^{+0.198}_{-0.141}$	(4)	No	No
12	Stem	4250	3700	60	154 ± 8	26:54.0±1.0	28:00.0±2.0	N/V	66.0±3.0	4543 ± 443	33.7±0.5	$0.503^{+0.156}_{-0.122}$	(5)	No	No
13	Stem	3350	3450	120	150 ± 8	30:11.0±10	31:06.1±0.1	V/V	55.1±10.1	3694 ± 874	8.0±0.5	$0.087^{+0.040}_{-0.034}$		No	No
14	Stem	2350	2500	300	138 ± 8	33:27.3±0.1	34:00.7±0.1	V/V	33.4±0.2	2060 ± 132	2.8±0.5	$0.054^{+0.028}_{-0.019}$		No	No
15	Stem	1300	1250	120	154 ± 8	36:05.5±0.1	37:03.5±0.1	V/V	58.0±0.2	3993 ± 221	4.0±0.5	$0.040^{+0.016}_{-0.011}$		No	No
16	Stem	650	700	300	150 ± 8	38:33.6±0.1	39:05.7±0.1	V/V	32.1±0.2	2152 ± 128	0.6±0.5	$0.011^{+0.020}_{-0.011}$		No	No
17	Stem	1300	1500	120	155 ± 8	41:03.6±0.1	41:57.3±0.1	V/V	53.7±0.2	3721 ± 206	0.9±0.5	$0.013^{+0.016}_{-0.009}$	(6)	No	No
18	Main Cloud	4800	5350	25	146 ± 8	47:07.5±0.1	48:08.0±0.1	V/V	60.5±0.2	3948 ± 229	18.7±0.5	$0.190^{+0.048}_{-0.035}$		No	No

* V = Visual; N = Nephelometer.

(1) Cyclone valve closed 0.4 sec. before exit.
(2) Cyclone valve closed 0.2 sec. before exit.
(3) Cyclone valve closed 3.7 sec. before exit.
(4) Cyclone valve closed 0.9 sec. before exit.
(5) Cyclone valve opened 27.0 sec. after entr
(6) Cyclone valve closed 12.8 sec. before e

3.6.3 Discussion

As indicated earlier, the total of 18 airborne dust samples taken after the Middle Gust IV event represent the most comprehensive set of data from all portions of a cloud (Table 10). Dust concentrations in the main cloud were one-third those measured in the Middle Gust III cloud. Middle Gust II was the only event with a lower yield at comparable times after detonation.

Particle density measurements were conducted in the laboratory on only one sample (Pass #4 - see Appendix VII). Size distributions were determined for the second sample in the main cloud as well as the first sample taken in the stem (Pass #4).

Fallout pans were located at 1000 feet and 2000 feet on radials, 0 degrees, 80 degrees, and 280 degrees. Pans were also located at 1000 feet, 2000 feet, 3000 feet, 4000 feet, and 5000 feet on the 40 degree and 320-degree radials. A sixth pan was located at 6000 feet on the 320-degree radial. The results are listed in Table 11 in terms of grams per square meter and are plotted on the map in Figure 8. The pattern was relatively symmetrical around ground zero with the bulk of the dust deposited within 2000 feet of the point of detonation. Fallout densities were low in comparison to the Middle Gust III measurements and in line with similarly low airborne dust concentrations in the cloud.

Three colors of F.P. were successfully released on the 45-degree radial; however, time and priorities did not permit a search of the airborne dust samples for fluorescent particles. The samples have been retained for future analysis.

The glass bead experiment was attempted again by leaving the beads in the shipping boxes and posting the boxes one foot off of the ground to avoid any problems with ground wetting. In this mode,

Table 11. Middle Gust IV - Fallout deposition.

Station (°)	Station (ft)	Mass/Area (gm/m^2)
0	1000	26.17
	2000	0.059
40	1000	5.013
	2000	0.022
	3000	0.235
	4000	0.0059
	5000	0.105
80	1000	3.37
	2000	0.016
280	1000	210.3
	2000	1.94
320	1000	7.82
	2000	0.308
	3000	0.196
	4000	0.039
	5000	0.0415
	6000	0.049

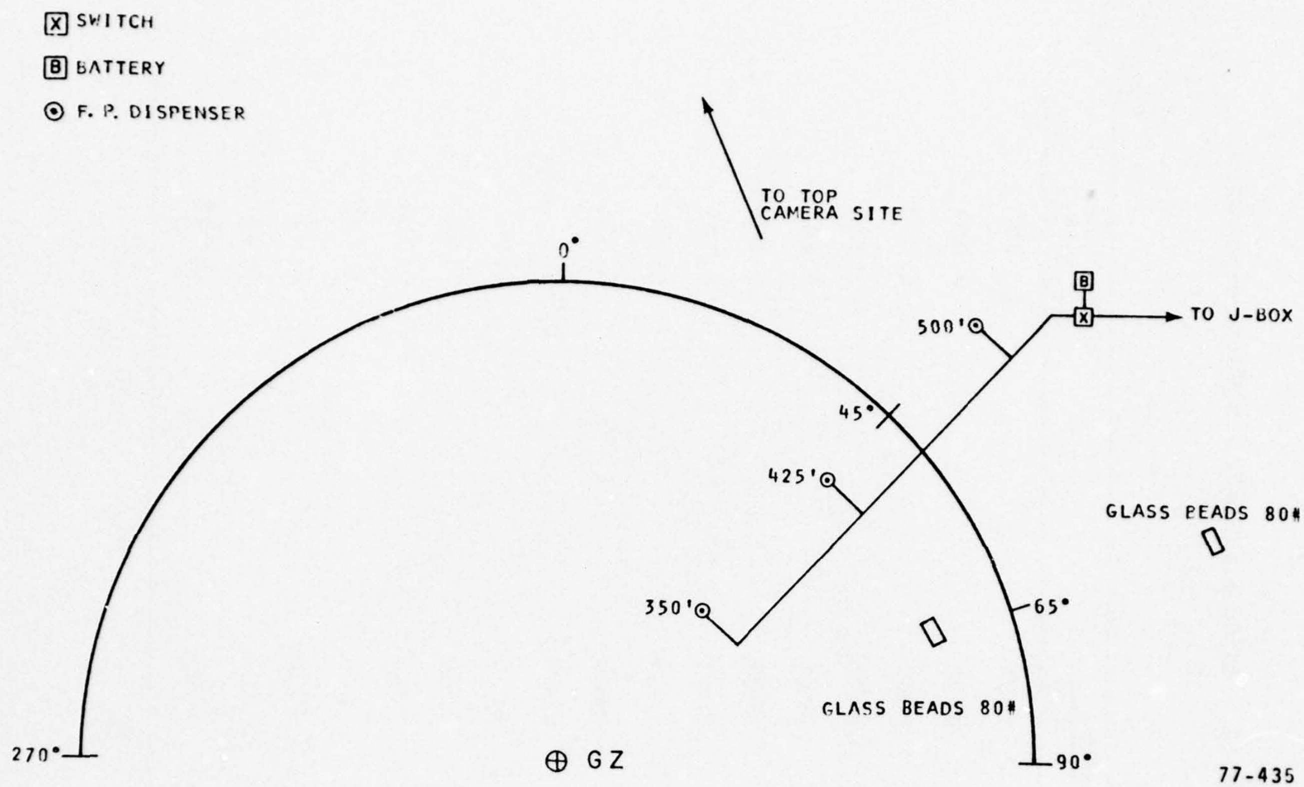

Figure 7. Middle Gust IV - Location of glass beads and fluorescent particle (F.P.) dispensers.

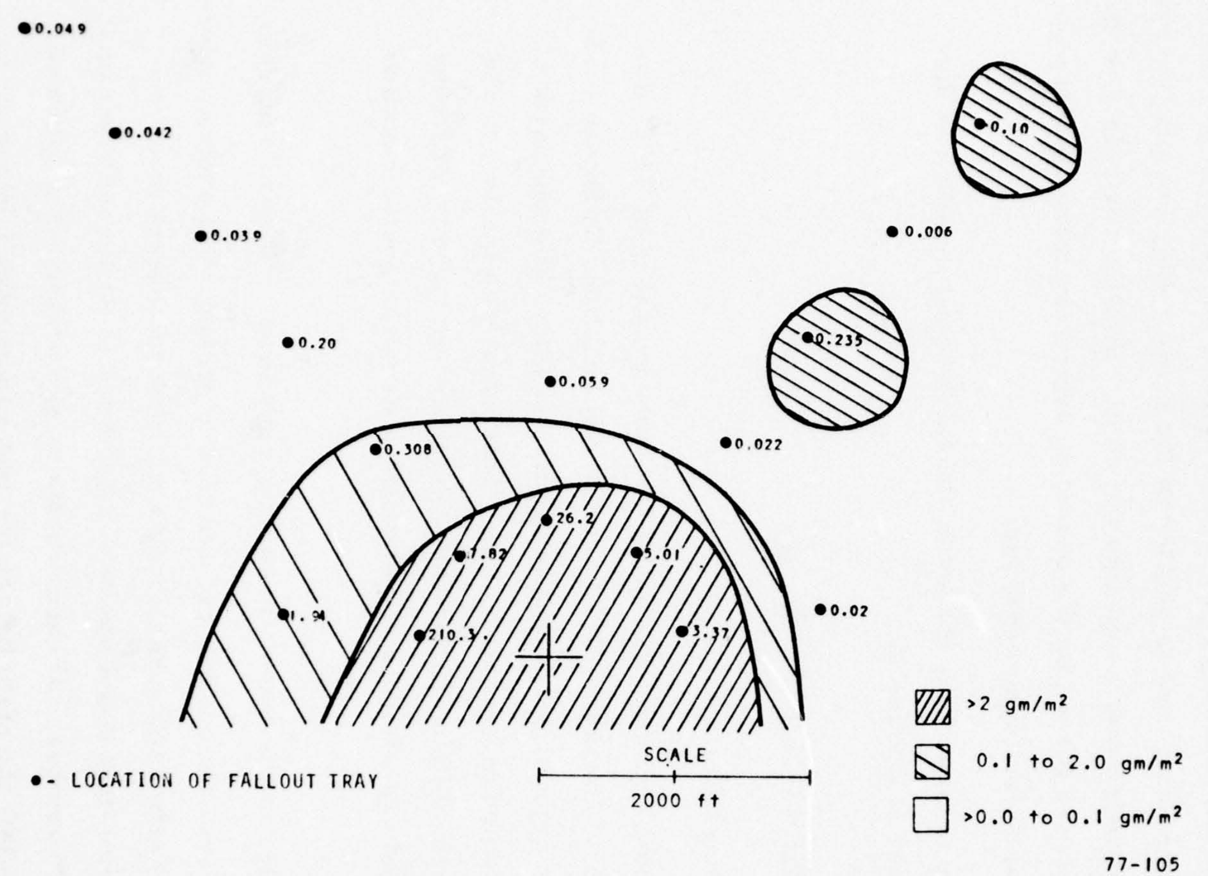

Figure 8. Middle Gust IV - Fallout pattern.

the beads served as a large puff source and did not simulate ground dust. The boxes were observed to shatter in the shock wave, creating a cloud of white dust which was swept into the stem. Similar restraints on time and the priorities forced by the upcoming Mixed Company III test prevented a search for these particles.

The nature of the airborne and fallout dust samples is discussed further in Section 4.

3.7 MIXED COMPANY III

3.7.1 General Conditions

Mixed Company III, a 500-ton tangent sphere of TNT, was detonated on 13 November 1972 near Grand Junction, Colorado. The location was approximately one-half mile west and slightly north of the Mixed Company I event in June. This event was the last of the series of seven Middle Gust-Mixed Company tests where MRI conducted ground experiments and sampled dust in the post-detonation clouds.

Prior to the event, ground operations were impeded by rain, some snow, and alternating wet and frozen ground. All ground experiments were emplaced successfully and, with the exception of one weather station that could not be serviced due to road conditions on the 13th of November, all experiments were carried out as planned. A light snowfall the night before the test caused minor problems in locating fallout and impact trays, but these were overcome within the pretest time period allotted. The preparation of the ground experiments, on-site problems, and performance during the test are contained in detail in Appendix IX.

3.7.2 Instrumentation and Experiments

The C-45 aircraft was flown with the following complement of instruments and sensors:

- Wet Cyclone
- Dry Cyclone
- Integrating Nephelometer
- Condensation Nuclei Counter
- Continuous Tape Sampler

In addition, temperature, altitude, indicated airspeed, and turbulence were measured.

A total of 20 passes (Table 12) was made under the cap cloud, through the stem, through the main cloud, and under the main cloud. The initial pass, under the rising cap of the cloud, was made at Z + 1:22.4 at an altitude of 2950 feet AGZ to collect large particles falling from the visible cloud shortly after the fireball lifted from the ground; the last pass was at Z + 65:15.9, after the aircraft left the residue of the cloud at an altitude of 7150 feet AGZ.

The sampling pattern was designed to collect maximum data under the cloud, shortly after detonation. Radar images of previous dust clouds have a distinct columnar appearance as opposed to the traditional mushroom shape of the visible cloud. Large particles, in excess of 1 mm, falling out of the cap or being expelled from the torus, were suspected to be the source of the image. The high radar cross section of these particles and the relative absence of large numbers of particles in the visible scattering range (0.1-1.0 micron diameter) below the cap and outside the stem would account for the difference between the radar and visual images of the cloud.

Table 12. Mixed Company III - Aircraft and dust data.

Event - MC III
Configuration - Tangent Sphere
Yield - 500 tons

Sampling Aircraft C-45
13 November 1972

Prevailing Wind Direction - W

Pass No.	Location	Alt. Above Gz (ft) Entry	Alt. Above Gz (ft) Exit	Hdg. (deg)	TAS ([illegible])	Entry (min:sec)	Exit (min:sec)	Criteria* Entry/ Exit	Δ t (secs)	Cloud Width (meters)	Total Dust (mg)	Dust Conc. (x 10^{-8} gm/cc)	Rmks.	Sized	Dens. Dist.
1	Under Cap	2950	3300	270	[illegible] ± 7	1:22.4 ± 0.3	1:25.8 ± 0.3	N/N	3.4±0.6	284 ± 61	21.6 ± 0.5	3.04 +1.23 -1.02		No	No
2	Under Cap	4150	4150	20	149 ± 6	2:45.2 ± 0.3	2:50.6 ± 0.3	N/N	5.4±0.6	360 ± 54	44.3 ± 0.5	4.93 +1.62 -1.29		Yes	Yes
3	Stem	4800	5000	180	170 ± 7	4:38.6 ± 0.3	5:03.1 ± 0.3	N/V	24.5±0.6	1862 ± 122	141.4 ± 0.5	3.04 +0.72 -0.51		Yes	Yes
4	Stem	4800	4650	280	185 ± 7	6:14.9 ± 0.3	6:42.3 ± 0.3	N/V	27.4±0.6	2266 ± 135	327.4 ± 0.5	5.79 +1.31 -0.92		Yes	No
5	Stem	3500	3450	70	181 ± 7	8:28.8 ± 0.3	8:48.8 ± 0.3	N/V	20.0±0.6	1618 ± 111	202.5 ± 0.5	5.01 +1.19 -0.85		Yes	Yes
6	Stem	3150	3350	210	171 ± 7	10:00.0 ± 0.3	10:18.7 ± 0.3	N/N	18.7±0.6	1429 ± 104	42.3 ± 0.5	1.19 +0.30 -0.22		No	No
7	Stem	3150	2750	330	215 ± 9	11:18.1 ± 0.3	11:43.4 ± 0.3	N/N	25.3±0.6	2431 ± 159	32.3 ± 0.5	0.532 +0.131 -0.095		No	No
8	Stem	2100	2200	180	197 ± 8	12:49.5 ± 0.3	13:05.8 ± 0.3	N/V	16.3±0.6	1435 ± 111	16.5 ± 0.5	0.460 +0.126 -0.095		Yes	No
9	Stem	4300	4400	90	154 ± 6	17:26.0 ± 0.3	18:17.0 ± 0.3	N/N	51.0±0.6	3511 ± 178	120.0 ± 0.5	1.37 +0.30 -0.21		Yes	No
10	Stem	6500	6450	300	168 ± 7	22:39.6 ± 0.3	23:54.5 ± 0.3	N/N	74.9±0.6	5625 ± 279	183.2 ± 0.5	1.30 +0.28 -0.20		No	No
11	Under Cloud	5200	5100	90	213 ± 9	25:49.8 ± 0.3	26:37.8 ± 0.3	N/N	48.0±0.6	4570 ± 250	61.8 ± 0.5	0.542 +0.124 -0.087		Yes	No
12	Under Cloud	5400	5500	270	193 ± 8	30:41.7 ± 0.3	31:26.1 ± 0.3	N/N	44.4±0.6	3830 ± 211	72.1 ± 0.5	0.754 +0.172 -0.121		No	No
13	Under Cloud	5500	5550	70	191 ± 8	34:21.9 ± 0.3	35:21.2 ± 0.3	N/V	59.3±0.6	5063 ± 263	83.4 ± 0.5	0.660 +0.148 -0.103		No	No
14	Main Cloud	6750	6600	260	183 ± 7	39:09.1 ± 0.3	40:28.2 ± 0.3	N/V	79.1±0.6	6470 ± 297	48.8 ± 0.5	0.302 +0.067 -0.047		Yes	No
15	Main Cloud	6500	6950	70	175 ± 7	42:45.1 ± 0.3	44:58.7 ± 0.3	N/N	133.6±0.6	10451 ± 465	68.9 ± 0.5	0.264 +0.057 -0.040		No	No
16	Main Cloud	7250	7050	250	180 ± 7	46:48.7 ± 0.3	48:00.4 ± 0.3	N/N	71.7±0.6	5769 ± 273	26.9 ± 0.5	0.187 +0.043 -0.031		No	No
17	Main Cloud	6850	7150	90	181 ± 7	50:05.1 ± 0.3	51:54.4 ± 0.3	N/N	109.3±0.6	8843 ± 391	26.1 ± 0.5	0.118 +0.027 -0.019		No	No
18	Main Cloud	7650	7450	270	191 ± 8	54:24.7 ± 0.3	55:45.3 ± 0.3	N/N	80.6±0.6	6881 ± 339	23.8 ± 0.5	0.139 +0.033 -0.023		No	No
19	Main Cloud	7650	7550	90	180 ± 7	60:20.3 ± 0.3	61:33.8 ± 0.3	N/V	73.5±0.6	5914 ± 278	28.3 ± 0.5	0.192 +0.044 -0.031		No	No
20	Main Cloud	7550	7150	270	193 ± 8	64:01.1 ± 0.3	65:15.9 ± 0.3	N/N	74.8±0.6	6453 ± 319	24.2 ± 0.5	0.166 +0.039 -0.028	(1)	No	No

* V = Visual; N = Nephelometer

(1) Cyclone valve opened 7.1 seconds after entry.

Size analysis of the sample collected on the second pass under the cap at Z + 2:45 indicated a distinct positive deviation from a normal distribution in the 100 to 600 μm diameter range.

Due to the plan to sample at early times under the cloud, the C-45 was not able to work in the main cloud until late in the dispersion of the cloud. After the first two passes under the cloud, the stem was entered at Z + 4:38.6. Eight passes were made through the stem, and the remaining passes were under or through the main cloud at various altitudes. Selected samples from the stem, under the cloud, in the cloud, and from the fallout network were analyzed for size distribution and particle density (Appendices V, VI, and VII).

A second aircraft was flown during Mixed Company III to collect gas samples as part of an environmental impact report relating to the overall effects of HE tests. This aircraft was the MRI Cessna 205 equipped with air pollution monitoring instruments to measure nitric oxide, carbon monoxide, and ozone. In addition, the aircraft was modified to collect total gas samples in 2-liter aluminized Mylar bags. Details of the sampling pattern and results of the gas analysis are contained in a special report included here as Appendix VIII.

Ground experiments included a comprehensive fallout network using special trays provided by Stanford Research Institute (SRI) (Figures 9 and 10). Location of the sampling stations was determined by MRI and implemented by SRI personnel. Sample weights, fallout density, and mass distribution were determined by SRI, while MRI performed additional size and particle density analyses. In addition, special grease-filled impact trays were installed to collect large fragile ejecta which would have broken up on impact with the hard surfaces of the fallout trays.

Five sequential fallout samplers were built and operated in the field. These devices collected fallout on an adhesive Mylar film which

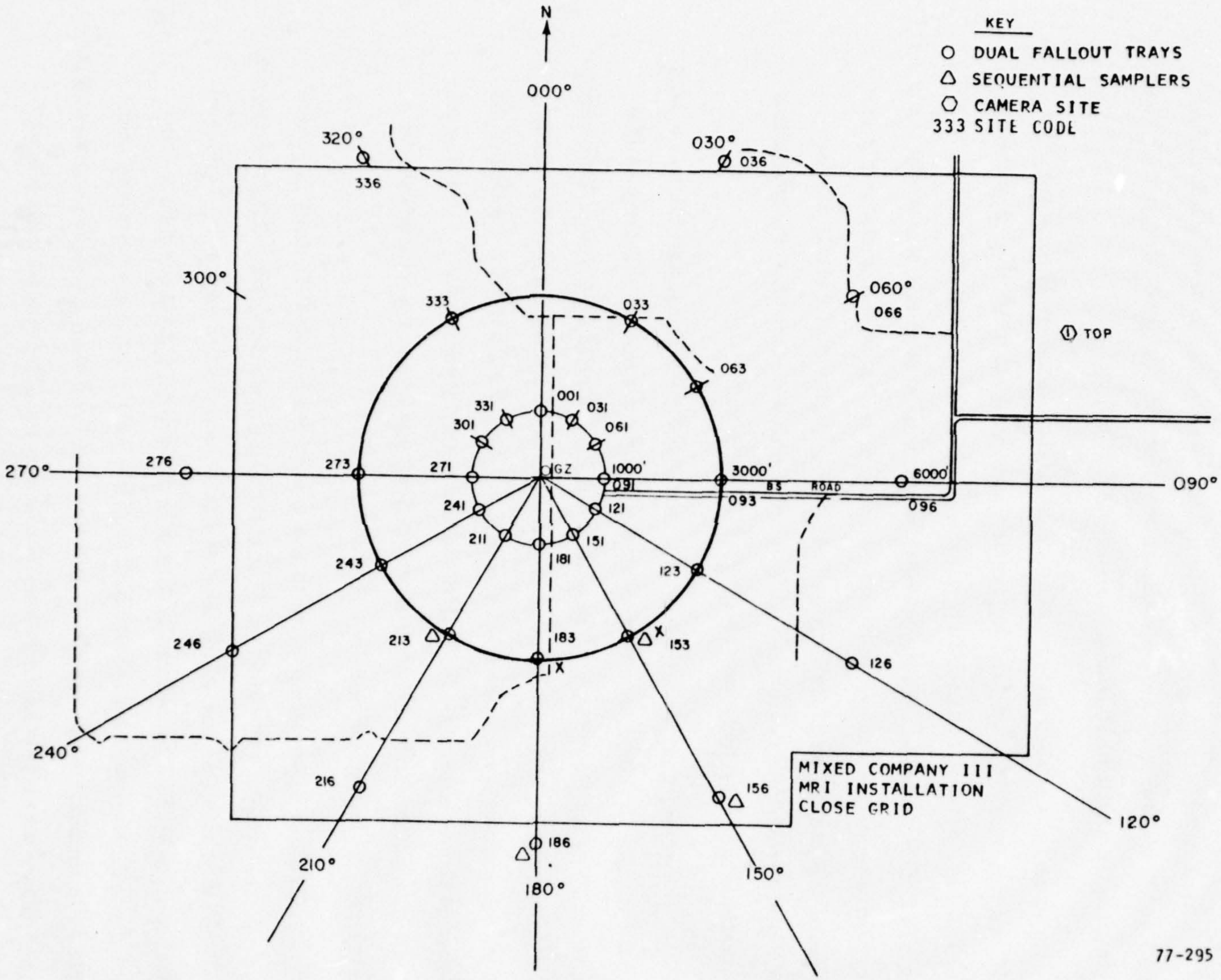

Figure 9. Mixed Company III - Fallout collectors close grid.

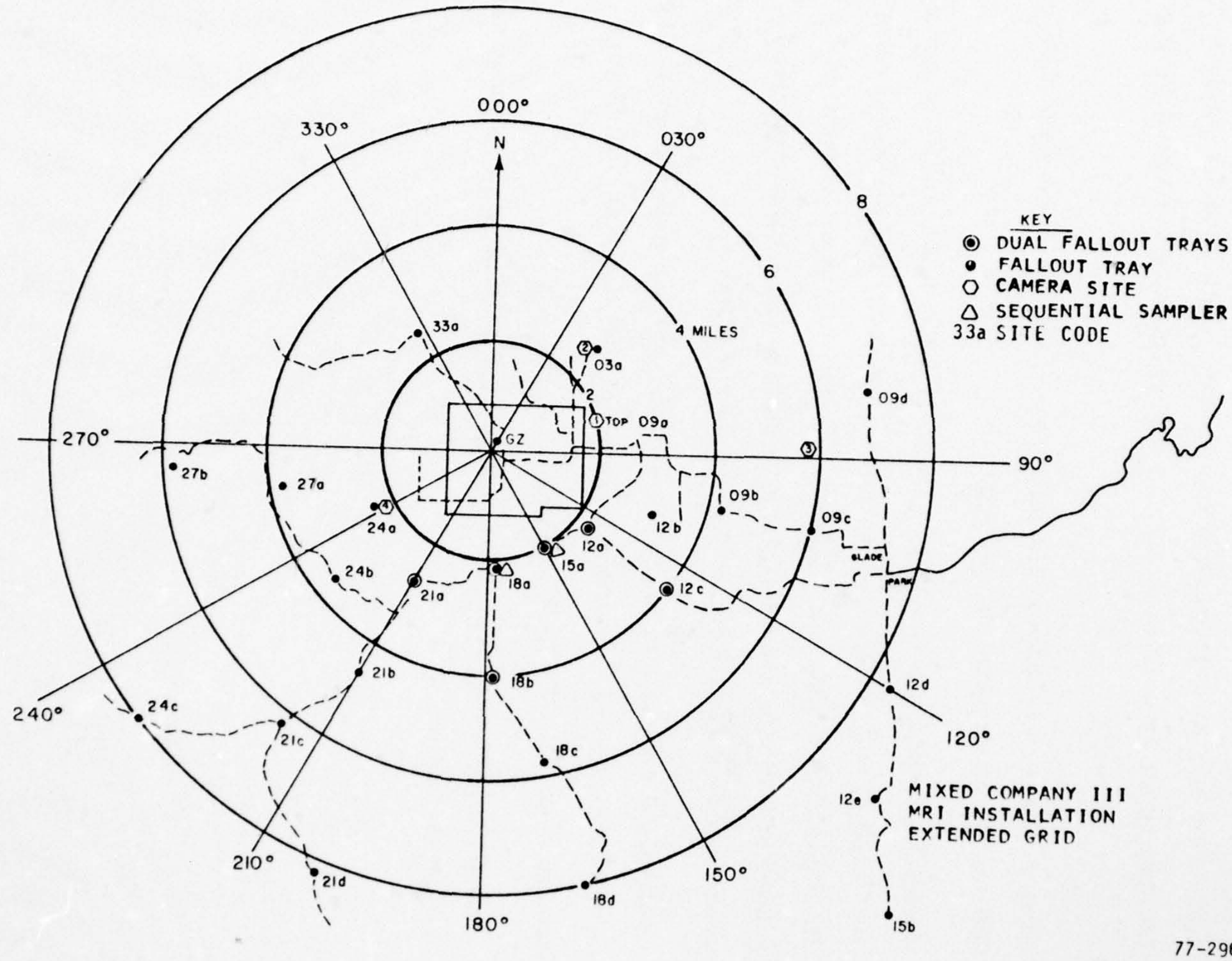

Figure 10. Mixed Company III - Fallout collectors extended grid.

passed a collection slit at a preprogrammed rate. The devices worked but were located in an area to the south of GZ which was bypassed by the cloud.

Five releases of fluorescent particles were made between 520 feet and 960 feet from ground zero (Figure 11).

Time-lapse photographs were taken at sites WSW and E of ground zero. IR and high speed (65 fps) films were shot from the technical observation point NE of the event. In addition, winds aloft were measured by MRI personnel at a site northwest of Battleship Rock. Additional wind data were provided by Jack Reed of Sandia Laboratories.

A detailed report and discussion of the ground experiments, locations, and performance is contained in Appendix IX (Ground Operations-Mixed Company III, 13 November 1972).

Results of the airborne dust sample and fallout analyses are discussed further in Section 4.

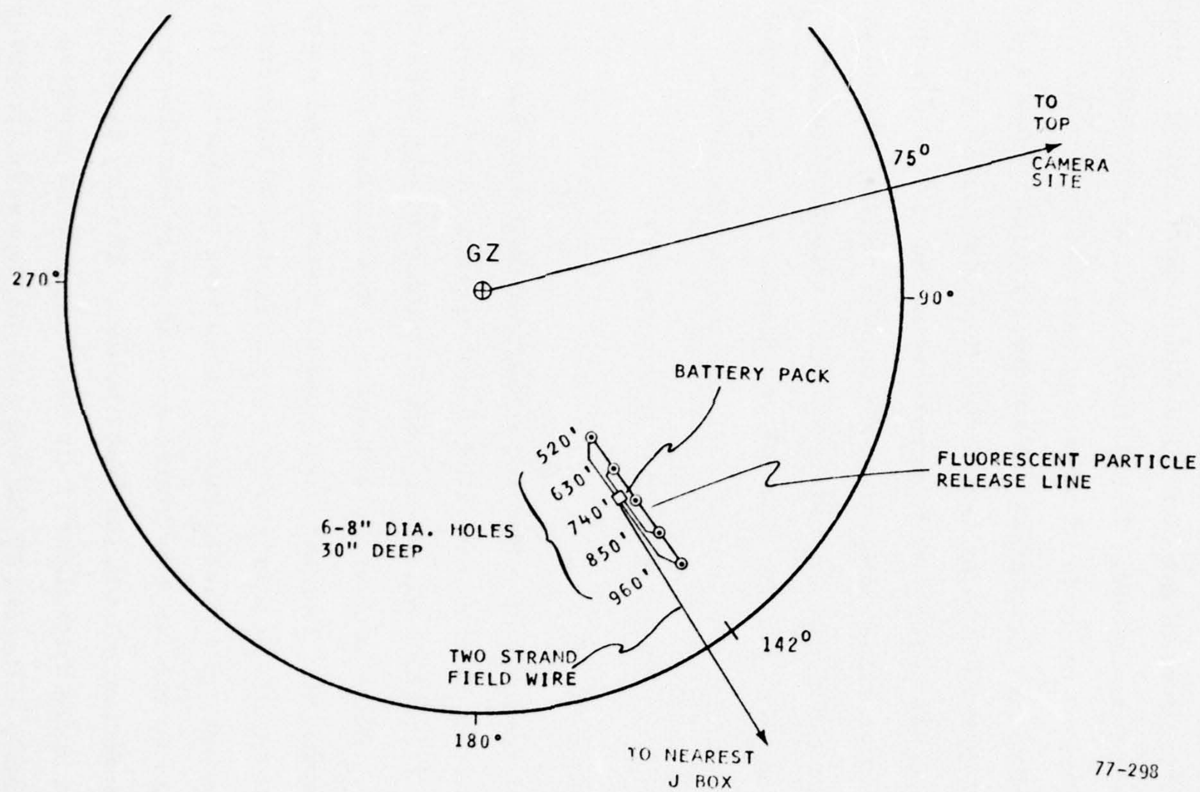

Figure 11. Mixed Company III - Fluorescent particle (F.P.) dispensers.

4. DISCUSSION AND CONCLUSIONS

4.1 INTRODUCTION

The objectives of the combined Middle Gust Mixed Company experiments were three-fold. The first objective was to develop, test, and evaluate various methods of collecting dust and other data inside the cloud shortly after detonation. Secondly, various methods of tracing the sweepup of dust were to be tested with the objective of determining if material from the apron was incorporated in the stem and main cloud. The third objective was to determine the spatial density of dust in various parts of the cloud, the size distribution of selected samples, the possibility of particle density changes as a function of the thermal environment, and the distribution of dust fallout from the cloud.

4.2 AIRCRAFT INSTRUMENT PERFORMANCE

4.2.1 Cyclone-Filter

Three methods of collecting integrated dust samples during passes through the cloud were tested: a wet cyclone, a dry filter, and a dry cyclone. Collection efficiency tests in the laboratory and from a moving vehicle indicated that the wet cyclone was the best choice for this type of sampling. The use of an internal water-alcohol spray assured that the walls of the cyclone were purged of all impacted dust and that the sample was flushed into the receiving container. The filter was limited by the air flow impedance caused by the filter and by problems of sedimentation in the filter holder. The dry cyclone had the advantage of a large throughput of air resulting in total samples 5 to 7 times the quantity collected by the wet cyclone; however, it suffered the same problems of sedimentation and blowby of fine particles experienced with the filter. The large quantity of dust collected by the dry cyclone did provide better statistical samples of the large particle portion of the size spectrum.

4.2.2 Condensation Nuclei Monitor

The condensation nuclei monitor (CNM) was used to measure the presence of submicron combustion particles. Instrument responses in all cases were minimal, indicating the lack of combustion products or ultra small mechanically generated aerosols. Some internal scavenging or agglomeration may have accounted for the depletion of these particles.

4.2.3 Fluorescent Particle Sampling

The fluorescent particle drum sampler operated satisfactorily; however, the sampling rate proved to be less than adequate for the concentrations of F. P. which were incorporated into the cloud. A technique for particle detection and counting which utilized the higher specific gravity of the (Zn, Cd)S particles was developed after the cyclone samples were returned to the laboratory.

The process of transferring the dust samples from the cyclone jars involved washing the contents of the jars into tall, flat-bottomed glass tubes which were subsequently dried slowly, overnight, at temperatures slightly above 100°C. As the dust settled in the tube, the heavier F. P. worked its way to the bottom of the tube. After drying was complete, the tube could be inverted, illuminated with ultra violet light, and the particles clearly seen and counted using a low magnification microscope.

Time and other priorities prevented a quantitative assessment of the relationships among the quantity of F. P. released, the distance from ground zero, ambient wind conditions before detonation, and the number of particles detected in the cloud. The data are available for future analysis if warranted.

Fluorescent particles were found in the samples collected in the stem of the Middle Gust I cloud. Possible particles were found in the main cloud of MG-II. None were found in any portion of the MG-III cloud, probably due to surface winds and the high rate of lateral translation of the cloud. Dust samples from MG-IV and MC-III were not examined but were saved for future reference.

4.2.4 Continuous Tape Sampler

The continuous tape sampler was flown on all the tests with the exception of Mine Throw I. The purpose was to collect spatially related samples of the large dust particles as the aircraft traversed the cloud. These data were intended as a complement to the nephelometer profiles of the fine particle distribution (less than 10 μm diameter).

The instrument worked satisfactorily within the limits of inertial impaction principles where there is some blowby and spreading of the sample on the moving tape. Visual examination of the clear tape showed spatial variations in the dust deposited as a function of the position in the cloud.

Due to other priorities and the need to evaluate the integrated dust samples from each pass before attempting to assess the internal distribution of dust in the cloud, the tapes were placed in storage for future analysis.

4.3 GROUND EXPERIMENT PERFORMANCE

4.3.1 Fluorescent Particles

The fluorescent particle releases were generally successful; however, on several occasions, one or more of the dispensers fired incompletely or failed to expel all the powder. In nearly all cases, powder was swept into the cloud. The failure to expel all the preweighed powder charge prevented any quantitative assessment of the volume of dust swept up.

4.3.2 Soil Simulants

The soil simulant experiments using sized glass beads and microbubbles were disrupted by wet ground and snow. In two cases (MG-I and MG-IV) where the beads were left packaged and were released by the bursting of the container in the shock wave, a visible cloud was seen in photographs and observed to move into the stem as the fireball lifted.

4.4 FALLOUT

The fallout experiments on MG-III, MG-IV, and MC-III were generally successful. The only loss was some samples on the 1000-foot ring around MC-III where the air blast and ground shock overturned the trays. Fallout concentration maps were prepared after each of the above tests.

The Middle Gust IV cloud experienced the least horizontal translation due to wind. With one exception, the maximum concentration at 2000 feet from GZ was ≤ 0.3 gm/m^2 (Figure 8). The maximum at 1000 feet was 210.3 gm/m^2 at one station, with values at the other 1000 foot stations ranging from 3.37 to 26.2 gm/m^2.

By contrast, the Middle Gust III fallout blanket at 1000 feet ranged from 5.28 to 5110 gm/m^2 (except for the station upwind of GZ which reported a value of 0.7 gm/m^2, Figure 4). Typical values at 1000 feet ranged from 30 to 100 gm/m^2. As significant was the fallout swath extending to the north east where the cloud was carried on 30+ knot winds. Four of the five stations between 2000 feet and 8000 feet reported concentrations ranging from 1.21 to 1.45 gm/m^2.

Both the fallout data, corrected for displacement due to wind, and the airborne in-cloud dust concentration indicate that the wet soil underlying the Middle Gust III site contributed to a quadrupling of the dust load lofted into the atmosphere.

The deposition at 1000 feet around the 500 ton Mixed Company III site (Figure 12) was comparable to the 100 ton Middle Gust III test. Values ranged from 16.4 to 138.7 gm/m^2. Beyond 1000 feet and extending over a mile and a half to the northeast, concentrations ranged between 18.7 and 23.1 gm/m^2, a factor of over ten times the concentration measured at similar distances from the detonation point of Middle Gust III. A "snowfall" of particles was experienced at the TOP, 2-1/2 miles from MC-III GZ and a value of 1.6 gm/m^2 was measured at a station due south of TOP at the same distance. 1.1 gm/m^2 was measured as far away as seven miles.

A factor of five increase in the size of the TNT charge should account for the large increase in the amount of dust lofted into the air regardless of the fact that MC-III was detonated over a dry coarser sediment than Middle Gust III or IV.

4.5 DUST DATA

4.5.1 Size Distributions

All size distributions were plotted in the standard form of Log $\eta_{T_i} \frac{D_i}{\Delta D_i}$ (cm^{-3}) vs Log D_i. This form permits identification of deviations from a normal straight line distribution typical of a homogeneous aerosol spectrum. (See Appendix IV for applicability of this form to the determination of particle number per volume of air sampled.) The supporting data and graphical presentations of these distributions are contained in Appendix V (Airborne Dust Samples) and Appendix VI (Fallout Dust Samples).

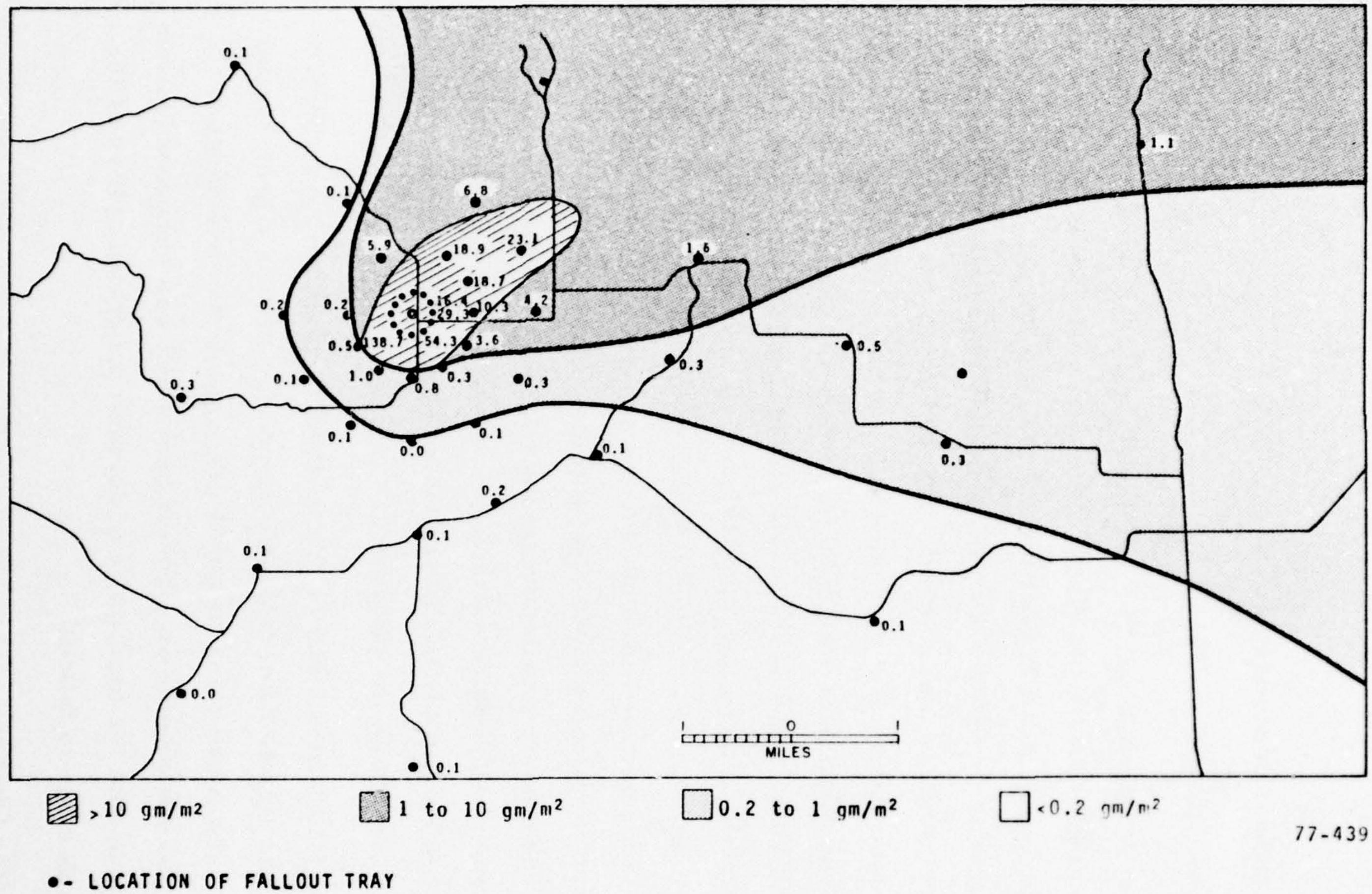

Figure 12. Mixed Company III - Mass fallout deposition measured by louvered fallout trays. (Heavy fallout occurred to the northeast several minutes after detonation.)

4.5.1.1 Airborne Dust Samples

- Middle Gust I

Two samples from the main cloud and three from the stem of the Middle Gust I cloud were sized. The dust collected on the first pass at Z+4:53.0 was enriched in particles in the 100-300 μm diameter range. Some particles larger than 1 mm in diameter were encountered: however, depletion due to fallout was evident. By the time of the second pass at 7:38.9, the distribution had smoothed with additional loss of the large particles. The third pass was 2000 feet below the second, near the top of the ground cloud and below the tail protruding from the main cloud. Dust concentrations were low, and the particle spectrum was relatively enriched in fine particles in the 20-40 μm diameter range. Some evidence of large particle enrichment was apparent and was probably due to fallout from the cloud above. The sample collected on Pass #4 was not sized. The material collected on the fifth and sixth passes came from the portion of the stem extending below the main cloud. These size distributions were similar to the second pass with progressive depletion of the larger sizes with the passage of time.

The MG-I cloud was characterized by peak concentrations of particles in the 100-300 μm diameter range due to either preferential production of these particles or zonal segregation due to internal circulation and sedimentation. The ground cloud was enriched in fines due to sweepup, and the total cloud underwent progressive loss of the larger particles due to fallout.

- Middle Gust II

None of the samples from Middle Gust II were sized because of the uncertainty in the exact location of the cloud relative to the overlying stratus deck.

- Mine Throw I

Only two samples from MT-I were sized, both in the stem. The sample from the first pass was processed but was lost due to an error in the handling procedure. Both samples from the upper stem (Pass #4) and the lower stem or ground cloud (Pass #7) were enriched in fine particles, reflecting the configuration of the charge which was totally coupled to the ground and thus produced a high degree of mechanical attrition. This was intensified by the loose alluvial soil and the fact that MT-I was detonated in a previous nuclear crater.

The Mine Throw I cloud contained extremely high concentrations of very fine dust resembling rock flour or clay.

- Middle Gust III

A total of nine samples from the MG-III cloud was analyzed in order to represent various portions of the cloud structure in space and time. The first pass at Z + 1:32.0 represents the earliest penetration of the main cloud during the Middle Gust-Mixed Company series. The measured size distribution was very consistent up to 600 μm diameter with some segregation due to fallout indicated above that limit. The distribution of particles on the second pass just below the base of the cloud was enriched in large particles throughout, including some which exceeded 1 mm in diameter.

Samples from various portions of the lower stem had normal distributions with slight anomalies due to settling of particles. On Pass #8 (Z + 10:48.4) at 5550 feet AGZ, some evidence of enrichment in the 80-220 μm diameter region appeared. This enrichment became very evident on Pass #9 at 7450 feet AGZ when samples were taken near the base of the cloud. Several hundred feet above, on Pass #10 in the base of the cloud, the anomaly disappeared.

The dust in the Middle Gust III cloud was characterized by a fairly regular size distribution with slight steepening of the slope as fallout removed the larger particles. Late in the development, a well-defined zone of particle segregation was identified just below the base of the cloud.

- Mixed Company I

The first sample under the cap of the Mixed Company I cloud at Z + 1:51.7 was not excessively enriched in large particles. Some particles larger than 1 mm in diameter were encountered; however, the principal deviation from a normal distribution occurred close to 100 microns in diameter. The second sample, in the stem at Z+3:20.1 and the ground cloud sampled on Pass #11, had similar distribution curves, implying that the nature of the soil, a weathered sandstone, may have controlled the size spectra of the dust cloud.

- Middle Gust IV

The size distribution of the dust in both the main cloud and the stem of the Middle Gust IV cloud approximated a straight line distribution up to 200-300 microns in diameter. Above that range, some removal of larger particles from the main cloud and a similar enrichment of these sizes in the stem was evident.

The lack of additional size distribution measurements prevents a detailed analysis of the redistribution of material in the cloud as a function of location or aging.

- Mixed Company III

The dust sampling aircraft made two passes under the cap of the main cloud at 1:22 and 2:45 minutes after detonation. The locations of these passes are indicated at the left of Figure 13. Pass #3 at 4:40 minutes was the first penetration of the stem.

At the right of Figure 13, the nephelometer traces and the quantity of dust recovered on each pass are shown. From Pass #1 to Pass #2, the dust recovery increased by a factor of two. On Pass #3, a triple peak was noted as the aircraft passed under the cap, through the stem, and back out under the cap. This pattern implies that dust is being released from a specific annular ring under the vortex. The absence of dust between this ring and the stem may account for cellular voids seen in the radar images of the cloud.

A total of eight samples from the Mixed Company III event were analyzed, representing early passes under the cloud and through the stem, and late passes through the stem and the main cloud. The second pass under the cap of the cloud at Z+2:45.2 did not reveal excessive numbers of large particles, as might have been expected. The principal deviation occurred in the numbers of particles between 100 and 500 microns in diameter, a deviation which was reflected in the fallout samples collected downwind (see Appendix IX, MCIII 6000 feet 60°) after the passage of the cloud.

The early samples in the stem (Passes #3 and #4) taken between 4:38.6 and 6:42.3 at around 4800 feet AGZ exhibited both enrichment of sizes near 100-200 microns in diameter and some sedimentation of particles in the 300-500 μm diameter range. At 3500 feet AGZ, 1300 feet below the altitude of Passes #3 and #4 and later near the ground (Pass #8 at Z+12:49.5), the distribution continued to maintain the same relationships between fine and large particles.

A pass at Z+25:49.8 under the main cloud produced material similar to the earlier stem samples at the same altitude but with progressive

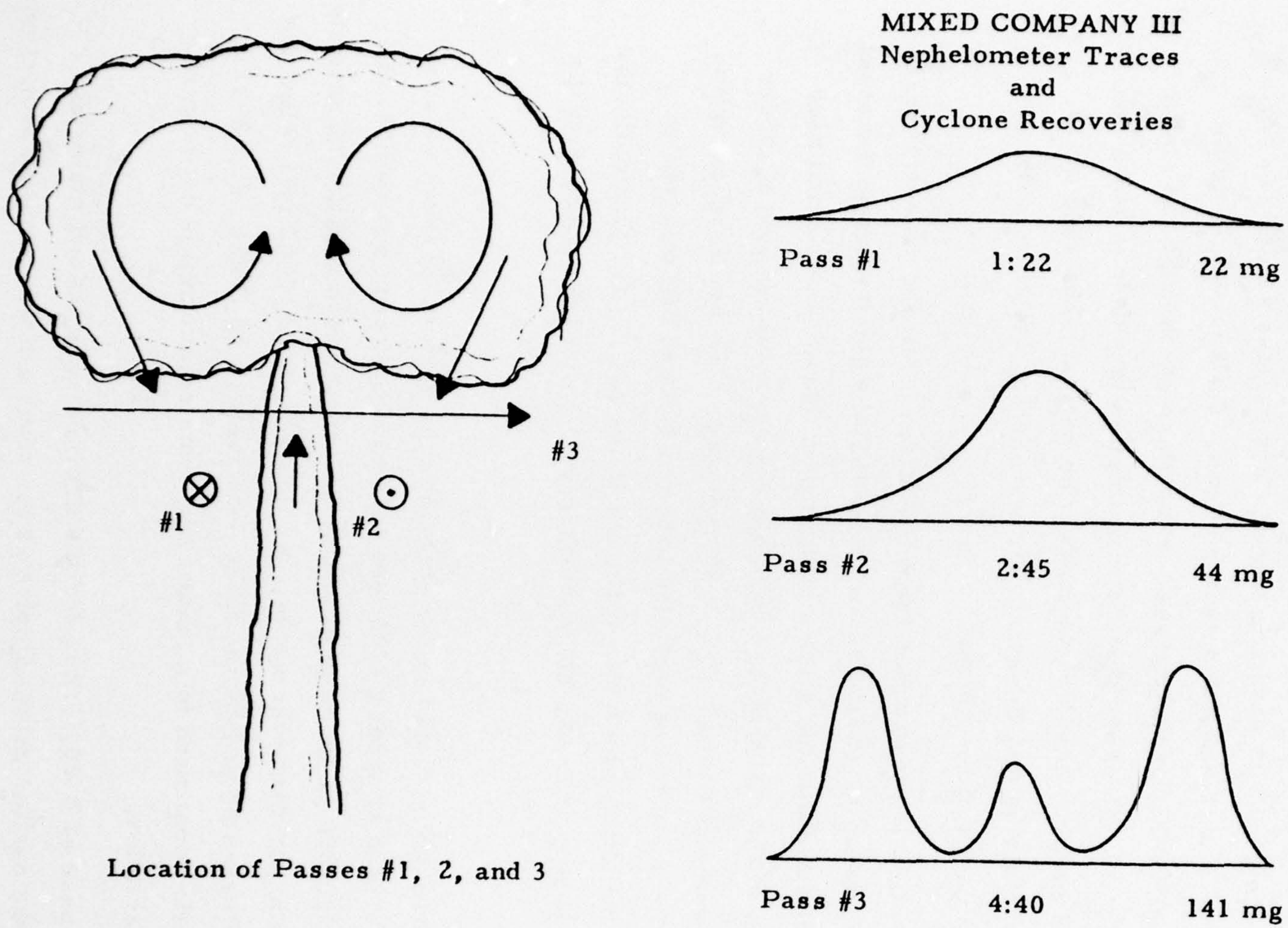

Figure 13. Mixed Company III - Location of Passes #1, #2, and #3 with respective nephelometer traces and dust cyclone recoveries. (Note zonal concentration of dust below main cloud.)

loss of the large particles. When Pass #3 and Pass #11 were normalized to a constant number of particles in the first bin (26 μm), depletions in the number of particles between 200-500 μm in diameter were noted.

Pass #14 was the first penetration of the main cloud and, as expected, the dust remaining was strongly depleted in large particles. Variations of over an order of magnitude were noted in the number of particles present at 160 μm diameter and above between the second and fourteenth passes.

The Mixed Company III event was characterized by the production of moderate numbers of particles in excess of a millimeter when compared to the Middle Gust tests; however, the contrasts in the overall size distributions were not great. The principal difference was a shift in the peak deviation of the distribution from the 100-300 μm diameter range seen in Middle Gust I and III to the 300-500 μm diameter range measured in the Mixed Company III samples. The effect of yield on the production and lofting of particles was best seen in the contrast between MC-I (20 tons) and MC-III (500 tons) where the peak moved from 100 microns to approximately 400 microns in diameter between the two tests.

4.5.1.2 Fallout Samples

- General

Selected fallout samples collected by Stanford Research Institute during the Mixed Company III event were sized using standard Taylor screens. These data are presented in Appendix X in terms of the weight retained on each screen and will not be discussed in this section.

In order to provide a direct comparison between airborne dust and resulting fallout, several samples collected under the path of the Middle Gust III, Middle Gust IV, and Mixed Company III clouds were analyzed by the Quantimet 720 technique.

- Middle Gust III

Three samples from MG-III, at 1000 feet, 2000 feet, and 8000 feet along the 60° radial, were analyzed for size distribution. At 1000 feet, the distribution was fairly uniform with a slight enrichment of 400-600 μm diameter particles and a surprising lack of material greater than a millimeter. Near 2000 feet, principal deposition consisted of particles in the 80-200 micron diameter range while at 8000 feet, most of the mass was contributed by particles in the 200-900 micron diameter size range.

The deposition of fine material near ground zero and the appearance of larger particles at great distances should reflect a combination of rapid cloud rise, high surface winds, and deposition from the ground cloud. The ground cloud, consisting of fine sweepup particles should deposit these close to the detonation site while the bulk of the material in the main cloud was still rising. Given 30-knot surface winds and a rise time of five minutes to stabilization altitude, the cloud would have passed over the 8000-foot collection pan approximately 2-1/2 minutes after detonation and at a time when it had just experienced its maximum vertical velocity. The appearance of large particles at 8000 feet may reflect the first arrival for true fallout from the main cloud.

- Middle Gust IV

The fallout deposited in two of the pans located at 1000 feet from ground zero during the Middle Gust IV test resembles closely the samples taken by the aircraft. Due to the slow movement of the cloud, the material collected at ground level appears to represent an integrated collection of sweepup and large particle fallout with some enrichment of material greater than 200 microns in diameter.

• Mixed Company III

The samples collected at 1000 feet and 3000 feet along the 60° radial of the Mixed Company III test are remarkably similar and devoid of segregation due to large particle fallout. When normalized, nearly all the error bars are coincident, and the total spectra appear to be consistent with material deposited from an homogeneous ground cloud. At 6000 feet, a distinct increase in the number of particles greater than 200 microns in diameter is noted with some of the bins increasing by an order of magnitude in the number of particles counted. Under the atmospheric conditions which prevailed on 13 November 1972 governing the rise and lateral movement of the dust cloud, and with knowledge of the distribution of material inside the cloud, it is safe to postulate that the fallout swath probably first touched ground within a distance of 5000-6000 feet from ground zero.

4.5.1.3 Microdensity Measurements

The microdensity measurements did not reveal any systematic variation in the mean particle density as a function of size for any of the tests. In several cases (MG-I, MT-I, MG-III), the largest particles proved to have the lowest density; however, the sampling statistics are poor, and many of these particles may be organic rather than altered mineral debris.

Middle Gust IV was the only test which produced particles with an abnormally low density throughout the size spectra. Both the stem and the main cloud contained a majority of particles with densities near 2.0 gm/cm^3.

Material sampled under the cap of the Mixed Company III cloud shortly after detonation had an overall mean density which was higher than material collected in the stem or in the fallout pans. An increase in the fraction of the total sample count composed of particles with a density of 2.68 gm/cm^3 in the 100-400 micron diameter range coincides with a similar increase in the fallout sample collected at 6000 feet; however, the data are subject to large variations and require an extensive statistical analysis before meaningful conclusions can be drawn.

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