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Technical Report

Summary of the Cloud Tracking and Sampling Experiments Conducted During the DIPOLE ORBIT and DIPOLE EAST Experiments

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Cloud tracking and sampling experiments were conducted for DIPOLE ORBIT and DIPOLE EAST events as a part of the Collateral Effects Experiments in an effort of the Defense Special Weapons Agency's Collateral Effects Programs to develop the capability to predict collateral effects from strikes on biological and chemical facilities. The results are summarized and analyzed.

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SUMMARY

The Defense Special Weapons Agency (DSWA) and the US European Command sponsored a Counterproliferation Advanced Concept Technology Demonstration (CP ACTD) to validate DSWA's Hazard Prediction and Assessment Capability, the model for release and transport of hazardous materials. The CP ACTD was a series of full scale field events, conducted at White Sands Missile Range, New Mexico, from December 1995 through February 1997.

A major component of each of the CP ACTD events was a real-time cloud tracking experiment in which the detonation cloud was observed by a suite of sensors which reported cloud positions to an operations center as the cloud was transported by the ambient winds. The operations center generated real-time predictions of the position and direction of motion of the cloud. This information was used to direct a mobile laboratory to the cloud position to measure the gaseous composition of the cloud and to position aerosol samplers to measure the particulate composition of the cloud at ground level.

An extensive data base was generated during the cloud tracking operations using infrared (IR) cameras, Fourier transform infrared (FTIR) spectroscopy, gas chromatography, lidars, visible video and scientific film photography, meteorology instruments, and aerosol samplers. This report integrates the information into a single source document that covers all of the cloud tracking and sampling experiments conducted on the CP ACTD events.

The events were (in chronological order) DIPOLE ORBIT 1 (3 December 1995), DIPOLE ORBIT 5 (11 June 1996), DIPOLE EAST 159 (20 July 1996), DIPOLE ORBIT 3 (10 December 1996, and DIPOLE ORBIT 6 (6 February 1997). Each of the five events was conducted in a different structure located at the DSWA Permanent High Explosive Test Site. Four new structures were constructed for the DIPOLE ORBIT events, which were detonations of BLU-109 penetrating weapons (static detonations and air drops). These were relatively weak structures that were expected to fail shortly after weapon detonation. Event DIPOLE EAST 159 was a

static detonation of a 29-kg TNT sphere in a relatively strong structure which was expected to remain intact.

The structures contained taggant gases, biological agent simulants, and rare earth oxide tracers which were released from the structures in the detonation clouds that were tracked by the sensor arrays. The taggant gases (sulfur hexaflouride and carbon tetrafluoride), which had strong IR emission bands, were used to make the detonation clouds "visible" to detection using IR instrumentation. The biological agent simulants were live bacterial spores with responses to weapon environments similar to those of bacterial warfare agents. Rare earth oxide tracers were mixed with the spores to aid in determining the survival rate of the spores in the detonation clouds.

The ability to track the detonation clouds was strongly affected by the weather, particularly the winds, which controlled the cloud motion, and the cloud cover, which influenced the radiometric contrast between the detonation cloud and the background for the IR sensors. The best cloud tracking conditions occurred with clear skies and consistent wind directions. The most difficult conditions were cloudy skies and light and variable winds.

The terrain affected the ability to maintain continuous cloud tracks when the clouds encountered elevated terrain which interrupted the lines of sight of the sensors. With consistent wind directions it was possible to predict the cloud tracks beyond elevated terrain encounters with sufficient accuracy to intercept the clouds with mobile sensors downwind of the elevated terrain.

The real-time cloud tracking and sampling operations were highly successful for all of the CP ACTD events. Clouds were tracked for substantial times and distances in a variety of conditions, as indicated in the following table.

For event DIPOLE ORBIT 1, the real-time cloud track determined by triangulation of the azimuths from multiple sensors was lost as the cloud crossed over elevated terrain at a range of 15 km and a time after the detonation of 75 min. One sensor, which could view the top of the cloud, continued to report the cloud azimuth to 90 min after the detonation. Additional real-time

Event	Winds	Maximum Tracking Range, km	Maximum Tracking Time, min	Maximum Range for Taggant Detection on Ground, km*	Maximum Range for Simulant Detection on Ground, km**
DIPOLE ORBIT 1	2-3 m/s, consistent direction	15	75	13	58
DIPOLE ORBIT 5	1-3 m/s, variable direction	2	35	8	7
DIPOLE EAST 159	1-3 m/s, variable direction	8	105	30	32
DIPOLE ORBIT 3	12-13 m/s, consistent direction	18	25	80	7
DIPOLE ORBIT 6	10-13 m/s, consistent direction	27	50	65	

* Detection by gas chromatograph in mobile laboratory.
**Presence of live spores and rare earth tracers in aerosol samples.

cloud acquisitions were reported by two sensors which relocated beyond the elevated terrain; however, these could not be confirmed during post-event analyses. The mobile laboratory did not reacquire the cloud beyond the end of the real-time track. Cloud tracking operations personnel were able to extrapolate the cloud track after loss of acquisition sufficiently accurately to permit the capture of aerosol samples on the ground at ranges of 28 and 58 km, well beyond the range of the real-time cloud track. Many of these samples contained measurable amounts of biological simulant and rare earth tracer.

The light and variable winds present during the DIPOLE ORBIT 5 event produced a completely different cloud-tracking scenario. The DIPOLE ORBIT 5 cloud dissipated rapidly and moved slowly, causing some difficulty in tracking. The triangulated track was lost at a range of about 2 km and a time after the detonation of 35 min. Cloud tracking operations personnel were able to direct the mobile laboratory sufficiently accurately to permit cloud intercepts at ranges to 8 km and times to 63 min, well beyond the range and time of the real-time cloud track. The ground sampling results were ambiguous.

The DIPOLE EAST 159 detonation cloud was tracked in real time to a range of approximately 8 km at a time of 105 min after the detonation. The mobile laboratory intercepted the cloud at ranges as great as 30 km from the structure 229 min after the detonation. Measured biological simulant and rare earth tracer were obtained along an extended path approximately 30 km from the structure, indicating that the cloud was very large at this distance. This was probably a result of the variable nature of the winds observed with instrumentation near the structure. The results for this event suggested that the techniques employed by the IR sensor operators substantially increased their ability to track the cloud in real time compared to post-event analysis of the sensor records.

The cloud tracking operations for event DIPOLE ORBIT 3 were the first conducted during high wind speed conditions. The real-time cloud tracking operations produced triangulated cloud positions at a range of 18 km at 25 min after the detonation. The mobile laboratory was successfully directed to positions where it intercepted the cloud at ranges to 80 km and times to 190 min after the detonation, after the cloud had passed over elevated terrain. This accomplishment conclusively demonstrated that the cloud could be reacquired by positioning the sensors using the predictive tools, wind measurements, and the initial real-time cloud track. The cloud path determined from the measured biological simulant and rare earth tracers was in excellent agreement with the real-time track for this event.

The cloud tracking operations for event DIPOLE ORBIT 6 were similar to those encountered during event DIPOLE ORBIT 3. The real-time cloud tracking operations produced triangulated cloud positions to a range of 27 km at 50 min after the detonation. The mobile laboratory was successfully directed to positions where it intercepted the cloud at ranges to 65 km and times to 110 min after the detonation after the cloud passed over the elevated terrain.

Overall, the cloud tracking operations for the CP ACTD events showed that detonation clouds could be tracked for distances as great as 27 km and times after the detonation as great as 105 min using IR sensors with sulfur hexafluoride as a gaseous taggant. These sensors provided triangulated results for cloud position for 2-5 times as long as the visible sensors (video and film cameras), which tracked the visible (dust) cloud. The lidars, which tracked the dust cloud, demonstrated their ability to obtain cloud azimuths, ranges, and dimensions independent of the optical sensors for a distance of 7.5 km and time after the detonation of 35 min, about 1.5 times as long as the visible sensors. When wind directions were consistent for periods of several hours cloud tracking operations personnel were able to predict the cloud paths, using the predictive tools, wind measurements, and the initial real-time cloud track, sufficiently accurately to successfully direct the mobile laboratory to cloud intercepts at ranges as great as 80 km from the structure.

PREFACE

This report was prepared by Science and Engineering Associates, Inc. (SEA), with the asistance of Logicon RDA, in compliance with the requirements of U.S. Army Engineer Waterways Experiment Station (WES) contract DACA39-96-K-0020. The work was sponsored by the Structures Laboratory of WES and was performed during the period 28 March 1996 through 31 December 1997. Mr. Paul W. Graham was the Contracting Officer's Technical Representative for the sponsor. The guidance and assistance provided by Mr. Graham, Mr. David B. Myers of the Defense Special Weapons Agency, and Dr. Gary P. Ganong of Logicon RDA are greatly appreciated.

CONVERSION TABLE

Conversion Factors for U.S. Customary to metric (SI) units of measurement.

MULTIPLY ⟶ BY ⟶ TO GET
TO GET ⟵ BY ⟵ DIVIDE

angstrom	1.000 000 x E -10	meters (m)
atmosphere (normal)	1.013 25 x E +2	kilo pascal (kPa)
bar	1.000 000 x E +2	kilo pascal (kPa)
barn	1.000 000 x E -28	meter^2 (m^2)
British thermal unit (thermochemical)	1.054 350 x E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical/cm^2)	4.184 000 x E -2	mega joule/m^2 (MJ/m^2)
curie	3.700 000 x E +1	*giga bacquerel (GBq)
degree (angle)	1.745 329 x E -2	radian (rad)
degree Fahrenheit	$t_K = (t^o f + 459.67)/1.8$	degree kelvin (K)
electron volt	1.602 19 x E -19	joule (J)
erg	1.000 000 x E -7	joule (J)
erg/second	1.000 000 x E -7	watt (W)
foot	3.048 000 x E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 x E -3	meter^3 (m^3)
inch	2.540 000 x E -2	meter (m)
jerk	1.000 000 x E +9	joule (J)
joule/kilogram (J/kg) radiation dose absorbed	1.000 000	Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 x E +3	newton (N)
kip/inch^2 (ksi)	6.894 757 x E +3	kilo pascal (kPa)
ktap	1.000 000 x E +2	newton-second/m^2 (N-s/m^2)
micron	1.000 000 x E -6	meter (m)
mil	2.540 000 x E -5	meter (m)
mile (international)	1.609 344 x E +3	meter (m)
ounce	2.834 952 x E -2	kilogram (kg)
pound-force (lbs avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 x E -1	newton-meter (N-m)
pound-force/inch	1.751 268 x E +2	newton/meter (N/m)
pound-force/foot^2	4.788 026 x E -2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535 924 x E -1	kilogram (kg)
pound-mass-foot^2 (moment of inertia)	4.214 011 x E -2	kilogram-meter^2 (kg-m^2)
pound-mass/foot^3	1.601 846 x E +1	kilogram-meter^3 (kg/m^3)
rad (radiation dose absorbed)	1.000 000 x E -2	**Gray (Gy)
roentgen	2.579 760 x E -4	coulomb/kilogram (C/kg)
shake	1.000 000 x E -8	second (s)
slug	1.459 390 x E +1	kilogram (kg)
torr (mm Hg, 0^o C)	1.333 22 x E -1	kilo pascal (kPa)

*The bacquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (GY) is the SI unit of absorbed radiation.

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SECTION 1
INTRODUCTION

1.1 BACKGROUND.

The Defense Special Weapons Agency (DSWA) has undertaken a program to develop the capability to predict collateral effects from strikes on biological and chemical facilities. The program included a Counterproliferation Advanced Concept Technology Demonstration (CP ACTD) to validate DSWA's Hazard Prediction and Assessment Capability (HPAC), the model for release and transport of hazardous materials. The CP ACTD was a series of full scale field events, conducted at White Sands Missile Range, New Mexico (WSMR), as a joint effort between DSWA and the US European Command (USEUCOM).

A major component of each of the CP ACTD events was a real-time cloud tracking experiment in which the detonation cloud was observed by a suite of sensors which reported cloud positions to an operations center as the cloud was transported by the ambient winds. The operations center generated real-time predictions of the position and direction of motion of the cloud. This information was used to direct a mobile laboratory to the cloud position to measure the gaseous composition of the cloud and to position aerosol samplers to measure the particulate composition of the cloud at ground level.

An extensive data base was generated during the cloud tracking operations using infrared (IR) cameras, Fourier transform infrared (FTIR) spectroscopy, gas chromatography, lidars, visible video and scientific film photography, meteorology instruments, and aerosol samplers. The IR cameras, FTIR spectrometers, and the lidars were used to track the expulsion clouds in real time. The other sensors and the aerosol samplers gathered information and samples which were analyzed post-event.

The results of the real-time cloud tracking experiments were published by the experimenters in reports and meeting minutes. The objective of this report was to integrate the information into a single source document that covers all of the cloud tracking and sampling experiments conducted on the CP ACTD events. The remainder of this section summarizes the five events on which cloud tracking and sampling experiments were conducted. Section 2 describes the sensors and measurements. Section 3 discusses the cloud tracking and sampler placement operations and delineates the specific sensor arrays deployed on each event. The results of the experiments are summarized in Section 4. Section 5 presents the conclusions of the authors. Section 6 is a comprehensive reference list.

1.2 EXPERIMENTAL PROGRAMS.

Cloud tracking and sampling experiments were conducted during five full scale events conducted at WSMR during the period from December 1995 through February 1997. These events were (in chronological order) DIPOLE ORBIT 1 (1145 hrs MST on 3 December 1995), DIPOLE ORBIT 5 (1337 hrs MDT on 11 June 1996), DIPOLE EAST 159 (1154 hrs MDT on 20 July 1996), DIPOLE ORBIT 3 (1052 hrs MST on 10 December 1996), and DIPOLE ORBIT 6 (1050 hrs MST on 6 February 1997). Two additional events, DIPOLE ORBIT 2 and DIPOLE ORBIT 4, were attempted but did not produce any results of significance for this summary due to weapon failures.

Each of the five events was conducted in a different structure located at the Large Scale Test Bed at the DSWA Permanent High Explosive Test Site (PHETS) (Figure 1-1). Four new structures were constructed for the DIPOLE ORBIT events (the same structure was used for events 2, 4, and 5). These were relatively weak structures that were expected to fail shortly after weapon detonation. The older Air Force 1 structure was modified for event DIPOLE EAST 159. This was a relatively strong structure which was originally constructed of reinforced concrete with one open side; the opening was closed with a steel wall for DIPOLE EAST 159. The following sections delineate the structure arrangements and outline the various experiments performed for each event.

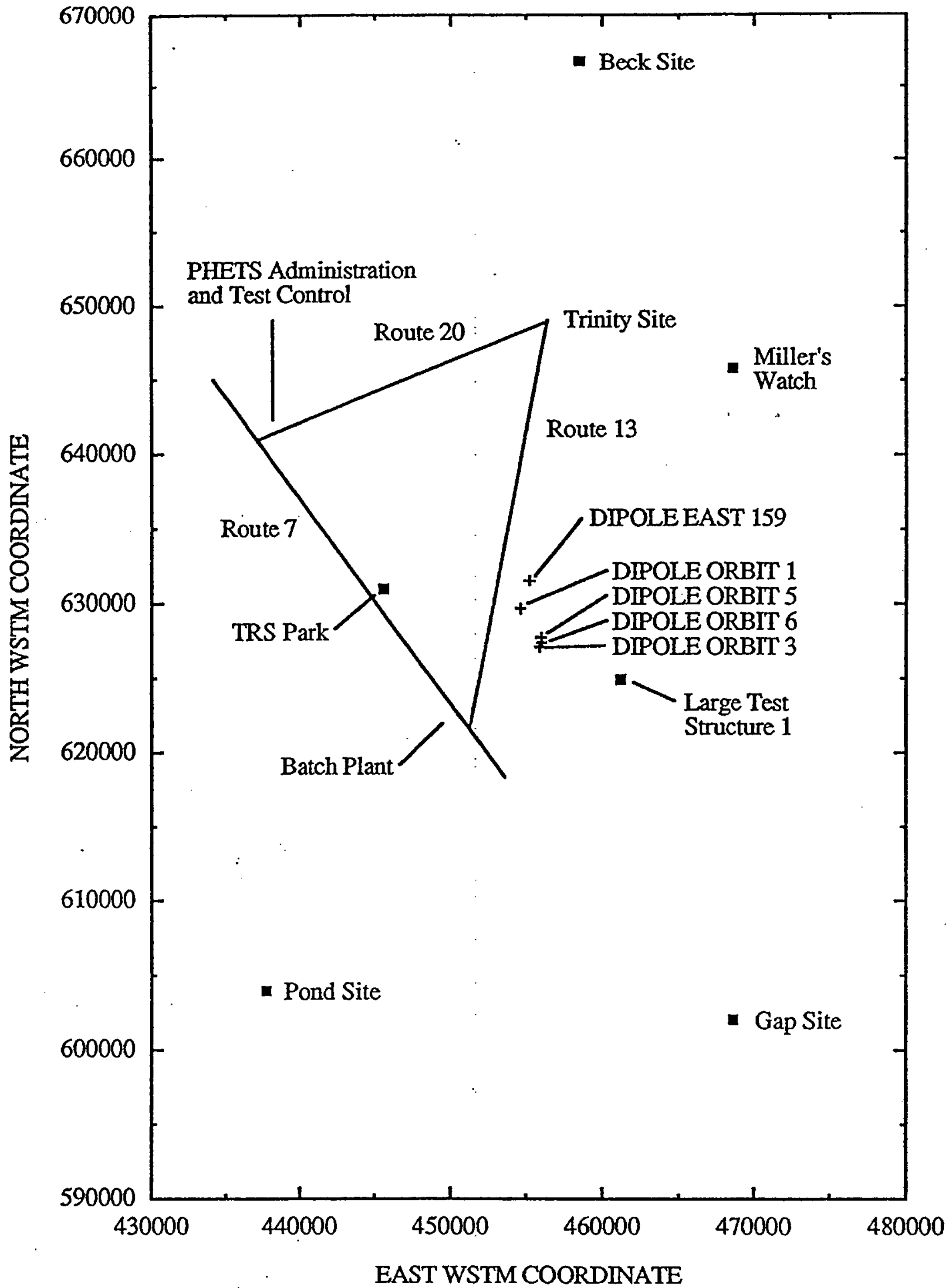

Figure 1-1. Structure locations on Large Scale Test Bed.

1.2.1 DIPOLE ORBIT 1.

DIPOLE ORBIT 1 was a static detonation of a BLU-109 weapon (penetrator only, containing approximately 243 kg (535 lb) of tritonal explosive) in the DIPOLE ORBIT 1 structure. The floor plan for this four room structure is shown in Figure 1-2. Details of the structure design are given by Martinez (1997). The weapon was suspended with the center of gravity at the mid height of the hallway between the doorways to rooms 1 and 3. A simulated weapon penetration opening was built into the roof above the weapon location.

The DIPOLE ORBIT 1 structure contained taggant gases, biological agent simulants, rare earth oxide tracers, and a number of articles of equipment typically found in biological warfare facilities (Martinez 1997). The equipment was non-functional.

The taggant gases were sulfur hexafluoride (SF_6) and carbon tetrafluoride (CF_4). These gases, which have strong emission bands in the 8-12 mm atmospheric window, were used to make the cloud "visible" to detection using IR instrumentation (Hall 1997). For DIPOLE ORBIT 1, bladders containing approximately 91 kg (200 lb) of SF_6 and 44 kg (96 lb) of CF_4 were placed in rooms 1, 2, and 4 (Martinez 1997).

The biological agent simulants were Bacillus thuringiensis var. kurstaki (Bt) and Bacillus subtilis var. niger (Bg) (Martinez 1997 and Ferry 1997). The Bt was purchased as DiPel Technical Powder and the Bg was provided by Dugway Proving Ground (DPG) (Ferry 1997). These were mixed with aluminum oxide (Al_2O_3) powder and the rare earth oxide tracers.

The rare earth oxide tracers were indium oxide (In_2O_3) and dysprosium oxide (Dy_2O_3) (Martinez 1997 and Ferry 1997). When mixed with the biological agent simulants the rare earth oxides provided a means for determining the quantities of the simulants in the cloud from captured aerosol samples. Neutron activation analysis (NAA) was used to determine the masses of the tracers in the captured aerosol samples (Mason and Finnegan 1997a and Ferry 1997).

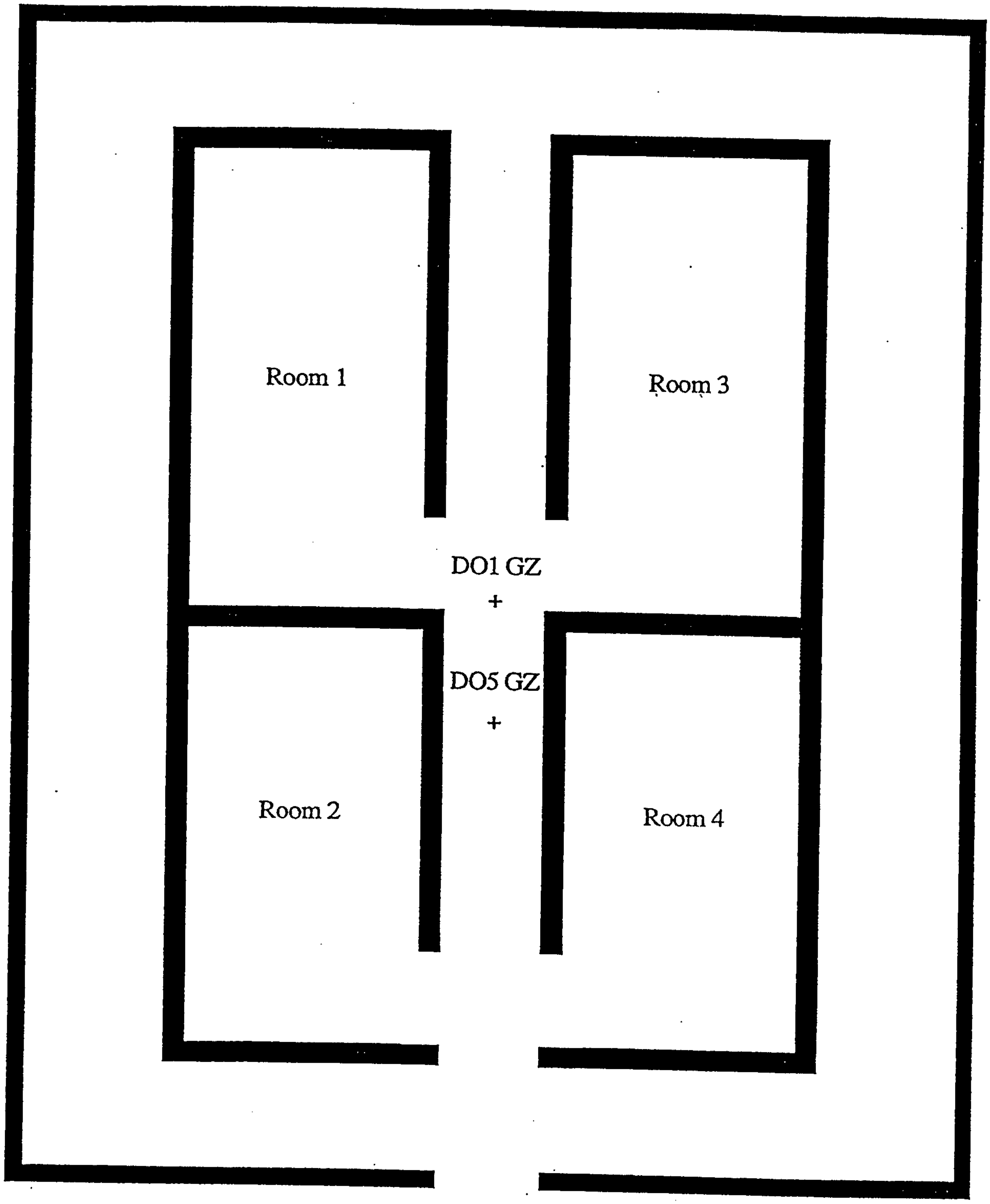

Figure 1-2. Floor plan for DIPOLE ORBIT 1 and 5 structures.

The biological production equipment included an autoclave, tissue culture equipment, an air filter, a computer, a motor generator, and other items (Ferry 1997). This equipment had no affect on the cloud tracking operations or results.

Pre-event releases of Al_2O_3 and SF_6 were conducted prior to shot day during dry runs. A continuous SF_6 release was conducted on the morning of the event to verify the wind direction at the test bed and aid in positioning the mobile tracking vehicle and the aerosol samplers.

The detonation of the BLU-109 inside the DIPOLE ORBIT 1 structure collapsed the roof into the structure and collapsed the front wall of the structure. As the structure failed, a plume containing detonation products, taggant gases, biological agent simulants, rare earth oxide tracers, and powdered structure materials (primarily concrete dust) was expelled from the structure. This plume formed the cloud which was tracked using the sensors described in Section 2.

1.2.2 DIPOLE ORBIT 5.

DIPOLE ORBIT 5 was a static detonation of a BLU-109 weapon (penetrator only) in the DIPOLE ORBIT 2/4/5 structure. The floor plan for this four room structure was identical to that for event DIPOLE ORBIT 1 (Figure 1-2). The weapon was buried beneath the hallway floor with the center of gravity 2.4 m (8 ft) below the floor. The weapon penetration opening from event DIPOLE ORBIT 2 was patched after that event. The penetration opening from event DIPOLE ORBIT 4 remained in the roof of the structure for event DIPOLE ORBIT 5.

The DIPOLE ORBIT 5 structure contained taggant gases, a biological agent simulant, rare earth oxide tracers, and articles of non-functional equipment (Davis 1996a). The taggant gases were SF_6 and CF_4. For DIPOLE ORBIT 5, bladders containing a total of 66 kg (146 lb) of SF_6 and 57 kg (126 lb) of CF_4 were placed in rooms 1, 3 and 4 (Herr *et al.* 1997a).

Bt was the biological agent simulant for event DIPOLE ORBIT 5 (Davis 1996a). The rare earth oxide tracers were indium oxide and dysprosium oxide. NAA was used to determine the masses of the tracers in the captured aerosol samples (Mason and Finnegan 1997a).

Pre-event SF_6 releases were conducted prior to shot day during dry runs. Puff SF_6 releases occurred on the morning of the event to verify the wind direction at the test bed and position the tracking vehicle and aerosol samplers.

The detonation of the BLU-109 under the DIPOLE ORBIT 5 structure collapsed the roof into the structure and displaced the front wall. As the structure collapsed, a plume containing detonation products, taggant gases, the biological agent simulant, rare earth oxide tracers, and concrete dust was expelled from the structure. This plume formed the cloud which was tracked using the sensors described in Section 2.

1.2.3 DIPOLE EAST 159.

DIPOLE EAST 159 was a static detonation of an uncased 29-kg (64-lb) TNT sphere in the Air Force 1 structure, which was a large single-room structure (Figure 1-3). The charge rested on a 0.6-m (2-ft) foam cube in a corner of the room 3 m (10 ft) from both walls. A 0.381-m (1.25 ft) x 0.394-m (1.29 ft) elliptic weapon penetration opening remained in the roof of the structure from a prior event (Espander 1996).

The DIPOLE EAST 159 structure contained taggant gases, a biological agent simulant, and a rare earth oxide tracer (Davis 1996b). The taggant gases were SF_6 and CF_4. For DIPOLE EAST 159, bladders containing a total of 88 kg (194 lb) of SF_6 and 38 kg (85 lb) of CF_4 were placed in the structure (Davis 1996b). Pre-event SF_6 releases were conducted prior to shot day during dry runs.

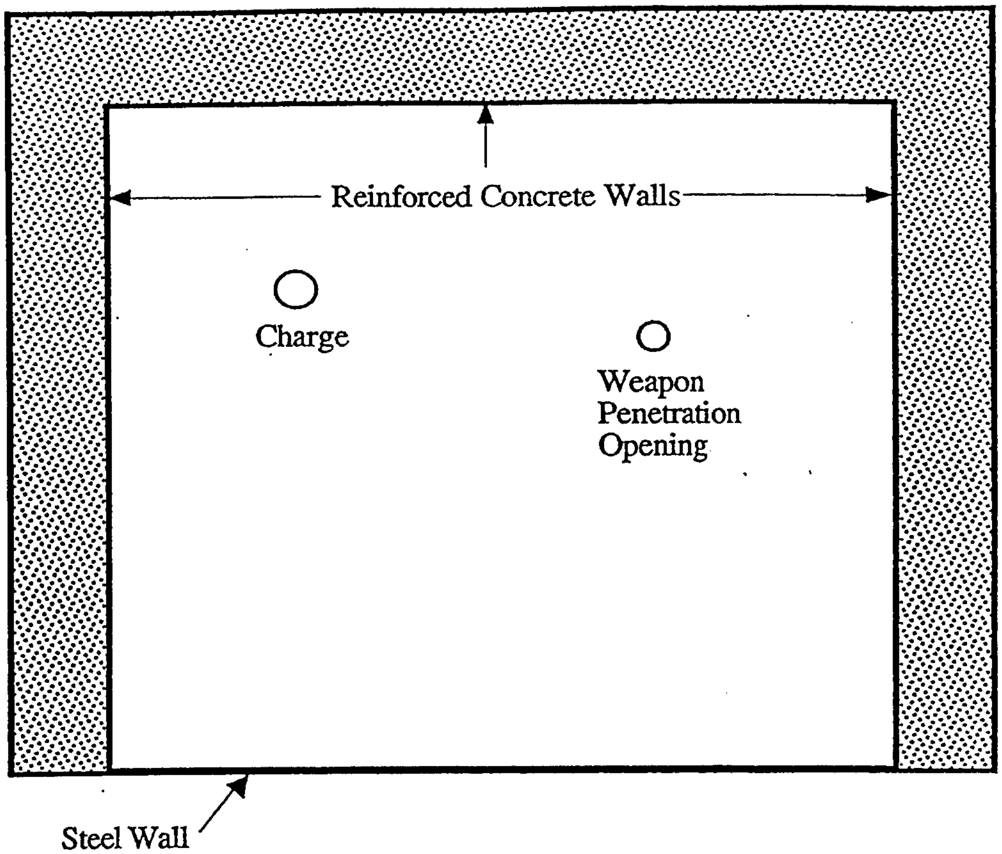

Figure 1-3. Floor plan for DIPOLE EAST 159 structure.

Bg was the biological agent simulant for event DIPOLE EAST 159 (Davis 1996b). The rare earth oxide tracer was indium oxide. NAA was used to determine the masses of the tracer in the captured aerosol samples (Mason and Finnegan 1996).

The detonation of the TNT charge inside the Air Force 1 structure pushed the steel wall outward producing a gap with an estimated width of 12.7 mm (Espander 1997). The plumes from this gap and the weapon penetration opening merged into a single plume containing detonation products, taggant gases, the biological agent simulant, and the rare earth oxide tracer. This plume formed the cloud which was tracked using the sensors described in Section 2.

1.2.4 DIPOLE ORBIT 3.

DIPOLE ORBIT 3 was an air drop of a GBU-24 (BLU-109) weapon into the DIPOLE ORBIT 3 structure. The floor plan for this four room structure was similar to the DIPOLE ORBIT 1 and 5 structures except that the rear hallway was eliminated and rooms 1 and 3 were extended to the back wall (Figure 1-4). There was some disagreement on the depth of the weapon center of gravity at detonation. Reinke *et al.* (1997) gave a range of 6.1-7.6 m (20-25 ft); whereas Rutland (1997) gave a best estimate of 6.1 m (19.9 ft).

The DIPOLE ORBIT 3 structure contained taggant gases, biological agent simulants, and rare earth oxide tracers (DeRego 1997a). The taggant gases were SF_6 and CF_4. For DIPOLE ORBIT 3, bladders containing a total of 91 kg (201 lb) of SF_6 and 46 kg (101 lb) of CF_4 were placed in rooms 1, 2 and 4 (Herr *et al.* 1997c). Pre-event SF_6 releases were conducted prior to shot day during dry runs.

Bt and Bg were the biological agent simulants for event DIPOLE ORBIT 3 (DeRego 1997a). The rare earth oxide tracers were indium oxide and dysprosium oxide. NAA was used to determine the masses of the tracers in the captured aerosol samples (Mason and Finnegan 1997b and Knudson 1997).

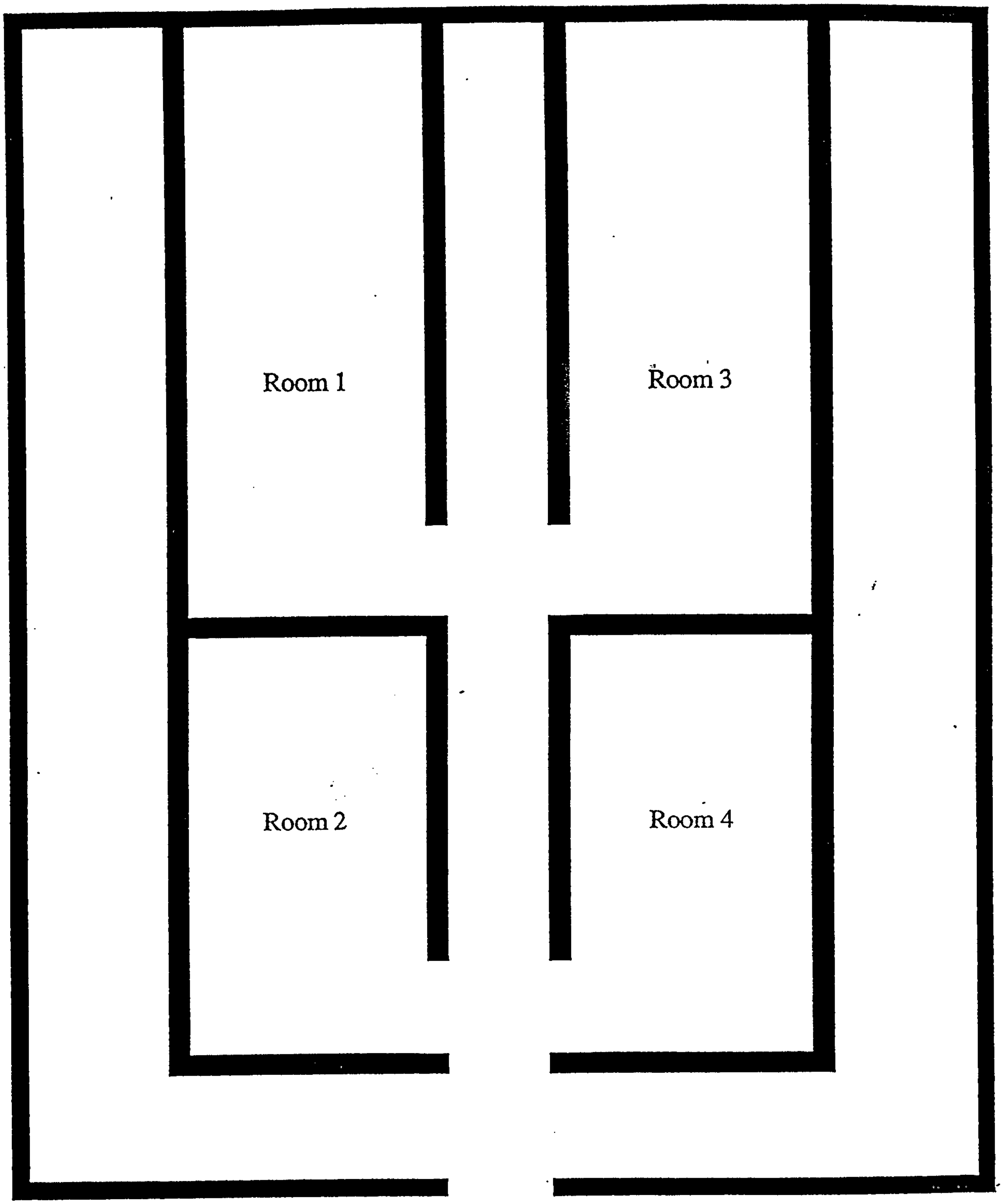

Figure 1-4. Floor plan for DIPOLE ORBIT 3 and 6 structures.

The detonation of the BLU-109 under the DIPOLE ORBIT 3 structure collapsed the roof into the structure. As the structure collapsed, a plume containing detonation products, taggant gases, biological agent simulants, rare earth oxide tracers, and concrete dust was expelled from the structure. This plume formed the cloud which was tracked using the sensors described in Section 2.

1.2.5 DIPOLE ORBIT 6.

DIPOLE ORBIT 6 was an air drop of a GBU-24 (BLU-109) weapon into the DIPOLE ORBIT 6 structure. The floor plan for this four-room structure was identical to the DIPOLE ORBIT 3 structure (Figure 1-4). There was some disagreement on the depth of the weapon center of gravity at detonation. Reinke *et al.* (1997) gave a range of 4.6-6.1 m (15-20 ft); whereas Rutland (1997) gave a best estimate of 4.0 m (13.2 ft).

The DIPOLE ORBIT 6 structure contained taggant gases, biological agent simulants, and a rare earth oxide tracer (DeRego 1997b). The taggant gases were SF_6 and CF_4. For DIPOLE ORBIT 6, bladders containing a total of 91 kg (201 lb) of SF_6 and 45 kg (98 lb) of CF_4 were placed in rooms 1, 2, 3, and 4 (DeRego 1997b). Pre-event SF_6 releases were conducted prior to shot day during dry runs.

Bt and Bg were the biological agent simulants for event DIPOLE ORBIT 6 (DeRego 1997b). The rare earth oxide tracer was indium oxide. No Bg was released in this event (Allen 1997).

The detonation of the BLU-109 under the DIPOLE ORBIT 6 structure collapsed the roof into the structure. As the structure collapsed, a plume containing detonation products, taggant gases, the biological agent simulant, the rare earth oxide tracer, and concrete dust was expelled from the structure. This plume formed the cloud which was tracked using the sensors described in Section 2.

SECTION 2
SENSORS AND MEASUREMENTS

Sensors for the DIPOLE ORBIT and DIPOLE EAST cloud tracking and sampling experiments included IR imagers (also referred to as IR cameras), FTIR spectrometers, a gas chromatograph, lidars, visible video and film cameras, wind indicators, and aerosol samplers (Martinez 1997). The various instruments are described in Sections 2.1 through 2.7 by instrument type, manufacturer (for some instruments), and general operating characteristics. For some instrument types, multiple instruments were mounted on various platforms which changed during the course of the experimental program. The operating characteristics also changed. Section 3 delineates the sensor arrays actually fielded on each of the five events.

2.1 INFRARED CAMERAS.

The Aerospace Corporation fielded IR cameras to map the spatial extent of the SF_6 cloud and provide cloud position (by triangulation with another sensor) and cloud dimensions (Hall 1997). Some of these instruments were operated on fixed platforms, others were mobile. These instruments provided near real-time results which the operators relayed to the cloud tracking operations center.

The cameras used for cloud tracking were Agema model 900 Thermovision 8-12 m IR cameras (Hall 1997). These were operated with coaligned visible video cameras. The IR camera imaging rate was 15 frames per second (fps). The operator observed the display at this rate. Several different modes were used for data acquisition.

In one mode the IR camera was equipped with computer controlled on- and off-band SF_6 filters (the on-band filter was a 10.6 mm narrow band optical filter). The system averaged on-band and off-band images and stored the data at a rate of one image per minute for post-event analysis. The data records also included the visible video images and IRIG-B timing from the Global Positioning Satellite (GPS) system. The camera mounts provided azimuth and elevation information.

In a second mode two co-aligned Agema model 900 IR cameras, one with an on-band (10.6 mm) filter and the other with an off-band (10.1 mm) filter, acquired images simultaneously (Herr *et al.* 1997a). This system displayed images to the operator at a rate of 15 Hz and stored images at the rate of 360 per minute for post-event analysis.

The Agema model 900 Thermovision 8-12 mm IR camera was also programmed to acquire high speed radiometric data, at millisecond resolution, to observe the initial plume from the roof vent (Hall 1997). The camera was switched from the high speed radiometric mode to the imaging mode after downloading the radiometric data.

An Inframetrics model 525 3-12 mm IR camera was used to aid in aiming an FTIR spectrometer. The instrument was mounted on a common base plate with the spectrometer and two visible video cameras with different fields of view. The IR camera was fitted with a 10.6 mm bandpass filter to pass the SF_6 emission (Hall 1997). The data records included IRIG-B timing from the GPS system.

The Aerospace Corporation also fielded an Agema 3-5 mm IR camera to measure the temperature of the initial plume in the high speed line scan mode. This camera used an on-band filter to pass the CF_4 emission at 4.58 mm (Herr *et al.* 1997b).

The U.S. Army Engineer Waterways Experiment Station (WES) fielded an Inframetrics IR camera in a mobile platform.

2.2 FTIR SPECTROMETERS.

The Aerospace Corporation fielded several FTIR spectrometers to determine the dimensions of the cloud and to quantify the amounts of the taggant gases SF_6 and CF_4 contained in the cloud (Hall 1997). They adapted the military M21 chemical agent detector, which was an 8-12 mm FTIR with an automated spectral recognition algorithm to identify chemical agents, for use as a portable spectrometer with full real-time spectral processing and display capability. One version was mounted in the Ram Van vehicle and used in the sidelooking mode. The pointing angle (azimuth and elevation) was stored with every spectrum.

A second 8-12 mm M21 FTIR spectrometer, mounted in the uplooking orientation, was used in the Tonka vehicle, which was a mobile laboratory with spectroscopic, gas sampling, and gas chromatography capabilities (Hall 1997). The FTIR instrument was identical to the sidelooking instrument, except that it was configured to view the sky at the zenith angle. This required that the Tonka vehicle maneuver beneath the SF_6/CF_4 cloud.

The Aerospace Corporation fielded a Block Engineering 8-12 mm sidelooking FTIR spectrometer (Hall 1997). Visible video cameras were coaligned with this instrument through a common elevation and azimuth mount with computer readout. The site using this sensor was called the Snoopy site.

The Aerospace Corporation fielded an Intellitec PSX 8-12 mm sidelooking FTIR spectrometer (a commercial version of the military M21 spectrometer), which was mounted in the TopKick vehicle (Herr *et al.* 1997d). Visible video cameras were coaligned to this instrument through a common elevation and azimuth mount with computer readout. The site using this sensor was called the Snoopy/Agema 1 site.

The U.S. Army Research Laboratory (ARL) fielded two 2-12 mm FTIR sidelooking spectrometers (Kantrowitz 1995). The Mobile Atmospheric Spectrometer (MAS) unit was mounted on a trailer. The Remote Sensing Rover unit was mounted in an off-road capable vehicle.

Phillips Laboratory (PL) fielded a Bomem 2-12 mm FTIR spectrometer. This instrument was used to examine the initial plume and for real-time cloud tracking.

2.3 GAS CHROMATOGRAPH.

The Aerospace Corporation gas chromatograph, which was contained in a mobile laboratory (the Tonka vehicle) was used to measure the SF_6 concentration in the cloud at ground level (Hall

1997). For cloud tracking purposes, the data from this instrument (together with the FTIR spectra from the uplooking spectrometer located in the same vehicle) verified the presence or absence of the cloud at the vehicle location. The inlet to the gas chromatographic system was approximately 6.4 m (14 ft) above the ground. The time from sample acquisition to readout was 2 min. Two loops were operated in a staggered fashion so that readouts were obtained at 1 min intervals. The lower detection limit of this instrument was from 5 to 19 ppt.

2.4 LIDARS.

The U.S. Army Chemical and Biological Defense Command (CBDCOM) and the Los Alamos National Laboratory (LANL) fielded the XM94 Long Range Biological Detection system (LR-BSDS) (Hungate *et al.* 1997). The light detection and ranging (lidar) systems, which were designated XM94-1 and XM94-2, provided real-time displays of the three dimensional cloud location, the relative particle concentration, and the approximate centroid.

Phillips Laboratory fielded a CO_2 doppler lidar instrument (Roadcap *et al.* 1996). This instrument was used to measure ambient wind velocities and to observe the detonation cloud.

2.5 VISIBLE VIDEO AND SCIENTIFIC FILM PHOTOGRAPHY.

Arrays of visible video and film cameras were fielded on the five events. Two approximately orthogonal pairs of video cameras were located to record the cloud dimensions and positions as functions of time. These cameras operated at the standard rate of 30 fps. For the static detonations all four cameras were manned so that the azimuths and fields of view could be adjusted as necessary to track the clouds. Only the most distant camera pairs were manned for the air drops. Similar arrangements were used for an orthogonal pair of large format (70 mm) film cameras. These cameras, which operated at 5 fps, were located at sufficient ranges to permit manned operations. Other cameras were fielded to record specific results such as the details of the initial plumes and the motion of the roof slabs. The data from these additional cameras are not discussed in this report. The visible video and film cameras were not used in the real-time plume tracking operations; however, the cloud tracks determined post-event using these instruments were suitable for comparison with those determined during the real-time operations (see Section 4).

2.6 RADIOSONDES AND OTHER WIND INDICATORS.

A balloon radiosonde was launched at the detonation time or a short time thereafter for each event. A slow rise rate was used for this balloon (about 100-200 m/min compared to the normal 300 m/min rise rate) to increase the vertical resolution of the data. This instrument provided profiles of meteorological parameters (wind direction and speed; temperature, pressure, and moisture content) during the initial stages of cloud transport from the structure. Additional instruments, including anemometers located at or near the structures, were also functional during some of the events. Additional radiosondes and ground-based instruments supported the weather prediction operations.

2.7 AEROSOL SAMPLERS.

Aerosol samplers were installed in a wide variety of configurations for the five events:

- within the structures,
- on mounts at doorways and platforms near the structures,
- in aerial arrays above the structures,
- on the ground surface near the structures (within about 300 m radius),
- in arrays on the ground surface far from the structures (> 1000 m).

Only results from the last sampling locations on this list are discussed in this report. These samplers were sufficiently far from the structure to permit correlation of the results of sampling operations with the cloud tracks. Many of the distant samplers were actually emplaced in real time using predicted cloud paths provided by cloud tracking operations.

SECTION 3

CLOUD TRACKING AND SAMPLER PLACEMENT OPERATIONS

3.1 CLOUD TRACKING OPERATIONS.

Cloud tracking operations consisted of an operations center team of Phillips Laboratory and Logicon RDA personnel, located at the PHETS Test Control Center (TCC), and the sensor operators, located at the fixed and mobile platforms around the test bed. Before some of the detonations, releases of SF_6 were made and the pre-event clouds were tracked by the FTIRs and IR cameras. These results, together with weather data and cloud path predictions, were used to position the mobile platforms for the detonations. Following the detonations the sensor operators reported the azimuths and elevations (and ranges for the lidars when available) to the TCC approximately every 5 min. The incoming cloud positions were plotted manually on a map and also entered into a portable computer. The instantaneous cloud position and direction of travel were estimated and the information forwarded to The Aerospace Corporation Tonka vehicle, which was required to maneuver under the cloud to obtain data, and to DPG personnel, who directed the placement of the aerosol samplers.

3.2 SAMPLER PLACEMENT OPERATIONS.

The aerosol samplers on the ground surface near the structures were emplaced pre-event. The samplers for the arrays far from the structure were loaded onto trucks which were parked downwind of the structure before the detonations. Using the predictions of the direction of cloud travel from cloud tracking operations, these samplers were placed along roads expected to intersect the cloud path. Samplers could also be retained on the vehicles to perform roving sampling operations.

3.3 SENSOR ARRAYS FOR TEST EVENTS.

The sensors described in Sections 2.1 through 2.4 were deployed in different arrays for the five events. The sensor arrays used for cloud tracking operations are summarized in Table 3-1. The specific arrangements for the five events are described in the following sections.

3.3.1 DIPOLE ORBIT 1.

3.3.1.1 Sensors for Tracking Operations. Eight optical sensor platforms were deployed for the DIPOLE ORBIT 1 event (most platforms contained multiple sensors). The platform names were used in the actual tracking operations. The initial stations for the sensor platforms for the DIPOLE ORBIT 1 event are shown by the circle symbols in Figure 3-1.

The Aerospace Corporation sensor platforms and major instruments all tracked the SF_6 cloud. These were:

522 site	Agema 8-12 mm IR camera + visible video
Snoopy site	8-12 mm FTIR spectrometer + Agema 8-12 mm IR camera + visible video
Ram Van	8-12 mm FTIR spectrometer + visible video
Tonka	8-12 mm FTIR spectrometer + gas chromatograph

The 522 Sensor was initially deployed on WSMR Route 13 south of its intersection with WSMR Route 7 and remained fixed during early cloud tracking operations for the DIPOLE ORBIT 1 event. Later, it relocated south of Mockingbird Gap along WSMR Route 12 approximately 5 miles west of the Oscura Range Center. At the first location data acquisition was started at T-5 min and continued to T+60 min. After calibration and relocation to the second site at T+170 min, data acquisition continued to T+240 min. Post-event analysis indicated that the apparent cloud detections from the second site could not be conclusively confirmed (Hall 1997).

Table 3-1. Sensor arrays for cloud tracking operations.

Agency	Sensor	D01	D05	DE159	D03	D06
Infrared Cameras:						
Aerospace	522 site Agema 8-12 µm	X				
Aerospace	Agema 1 8-12 µm		X	X	X	X
Aerospace	Agema 2 8-12 µm		X	X	X	X
Aerospace	Agema 3 8-12 µm			X	X	X
Aerospace	Snoopy site Agema 8-12 µm	X				
Aerospace	Snoopy site 3-5 µm			X		
WES	Inframetrics			X		
FTIR Spectrometers:						
Aerospace	Snoopy site 8-12 µm*		X	X		X
Aerospace	Ram Van 8-12 µm	X	X	X	X	X
Aerospace	Tonka 8-12 µm**	X	X	X	X	X
ARL	MAS 2-12 µm	X				
ARL	Rover 2-12 µm	X				
PL	Bomem 2-12 µm		X			
Lidars:						
LANL/CBDCOM	XM94-1	X				
LANL/CBDCOM	XM94-2	X				
PL	Doppler			X		
Gas Chromatography						
Aerospace	Tonka	X	X	X	X	X

*The Snoopy FTIR spectrometer was used to measure the detonation cloud spectral characteristics at early times and not in cloud tracking operations for DIPOLE ORBIT 1.
**The up-looking FTIR in Tonka was used to verify cloud position, not for actual cloud tracking.

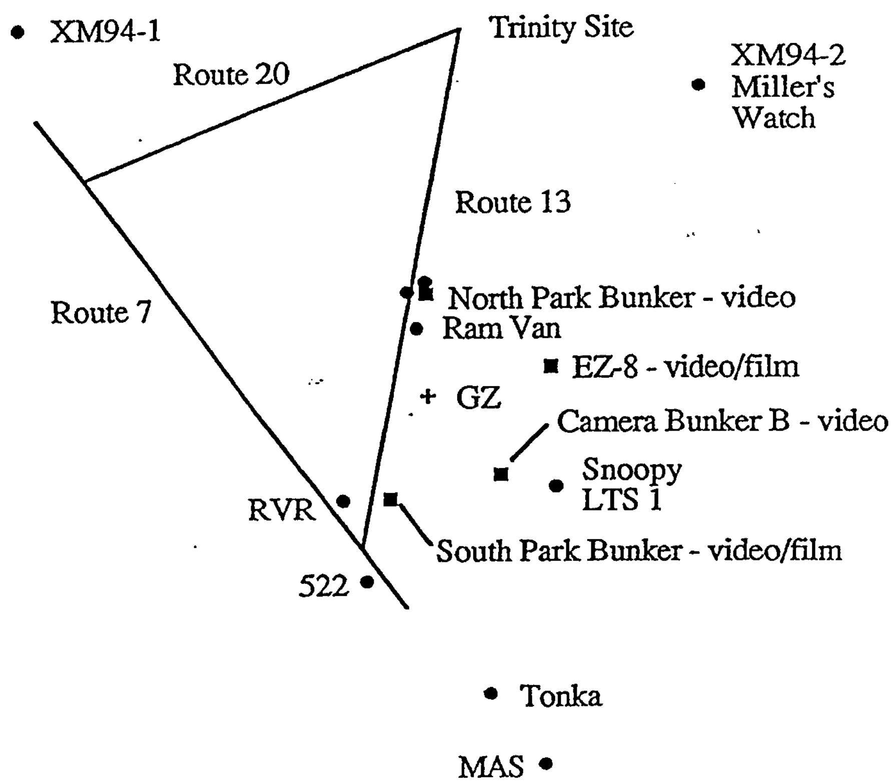

Figure 3-1. Initial stations for the sensor platforms for event DIPOLE ORBIT 1.

The Snoopy site remained fixed on the roof of the LTS 1 structure during cloud tracking operations for the DIPOLE ORBIT 1 event. The IR camera was used to measure the roof vent plume temperature and for cloud tracking. The FTIR spectrometer was used to measure the detonation cloud spectral characteristics at early times and not in cloud tracking operations for the DIPOLE ORBIT 1 event.

Ram Van was a mobile platform which remained fixed at its location on WSMR Route 13 northwest of the DIPOLE ORBIT 1 structure during cloud tracking operations for the DIPOLE ORBIT 1 event. Vertical and horizontal profiles of the cloud were obtained using the Ram Van spectrometer.

Tonka moved nearly continuously before and after the detonation. Before the detonation it maneuvered under the track of a pre-event SF_6 release to obtain an optimum position relative to the DIPOLE ORBIT 1 structure. Its position at the time of detonation was on WSMR Route 7 near Mockingbird Gap. After the detonation it was directed to the estimated cloud location by cloud tracking operations personnel.

The ARL spectrometers tracked the SF_6 cloud:

MAS	2-12 mm FTIR spectrometer
Rover	2-12 mm FTIR spectrometer

The MAS remained fixed along WSMR Route 7 near Mockingbird Gap during cloud tracking operations for the DIPOLE ORBIT 1 event. The Rover remained fixed near the batch plant on WSMR Route 7 during early cloud tracking operations. Later, it relocated south of Mockingbird Gap.

The LANL/CBDCOM lidars tracked the particulate cloud:

XM94-1	lidar (designated Photon 1)
XM94-2	lidar (designated Photon 2)

The XM94-1 and XM94-2 systems remained fixed at locations on WSMR Route 7 north of the PHETS administration area and at Miller's Watch, respectively, during cloud tracking operations for the DIPOLE ORBIT 1 event. These instruments were restricted from scanning lower than 0.5 degrees above the horizon for eye safety reasons. Because of this restriction the XM94-2 system did not contact the cloud until 1 min after the detonation. Also, real-time ground locations were not available, although the elevations could be calculated by numerical analysis (Hungate *et al.* 1997). The XM94-2 sustained a scan motor problem prior to 15 min after detonation and the XM94-1 was in an overheated condition prior to 40 min after detonation. The two lidar systems participated in the real-time cloud tracking operations for DIPOLE ORBIT 1. Additional results were delivered to DSWA the day following the event (Hungate *et al.* 1997).

3.3.1.2 Visible Video. The visible video cameras for post-test determination of the cloud track and dimensions were located at North Park Bunker, South Park Bunker, EZ-8, and Camera Bunker B for event DIPOLE ORBIT 1 (square symbols in Figure 3-1). All of these sites were manned. The cloud was tracked until 20 min after the detonation and reduced results were obtained for this time period (Allen and Ball 1997).

3.3.1.3 Scientific Film Photography. The large format film cameras for post-test determination of the cloud track and dimensions were located at South Park Bunker and EZ-8 for event DIPOLE ORBIT 1 (square symbols in Figure 3-1). These sites were manned. Reduced results were reported for 10.5 min after the detonation (Dudziak 1997a).

3.3.1.4 Radiosondes and Other Wind Indicators. The "slow rise" radiosonde was launched at 1145 hrs, coincident with the DIPOLE ORBIT 1 detonation. Continuous data were also acquired by three anemometers located on the sampler array which was suspended over the structure and at the 15 and 30 m heights on a 30 m (100 ft) tower located near the Air Force 1 structure (Jameson 1997). The tower data were recorded at 1 min intervals (Davis 1996a).

3.3.1.5 Aerosol Samplers. For event DIPOLE ORBIT 1, 3 aerosol particle sizers, 6 slit samplers, and 40 Wagner samplers were placed pre-event approximately 280 m south-southeast of the structure in a 90-degree arc (Martinez 1997). An additional 12 slit samplers and 60

Wagner samplers were placed approximately 910 m south-southeast of the structure in a 90-degree arc.

During cloud tracking operations 80 samplers were placed at 27.8 km and 10 samplers were placed at 57.7 km. Roving samplers were also used at 11 locations (Larsen 1996a).

3.3.2 DIPOLE ORBIT 5.

3.3.2.1 Sensors for Tracking Operations. Six optical sensor platforms were deployed for the DIPOLE ORBIT 5 event (Table 3-1). The initial stations for the various platforms for the DIPOLE ORBIT 5 event are shown in Figure 3-2.

The Aerospace Corporation sensor platforms and major instruments all tracked the SF_6 cloud (Herr *et al.* 1997a). All Aerospace platforms except Tonka remained fixed during cloud tracking operations for event DIPOLE ORBIT 5. The platforms and instruments were:

Agema 1 site	Dual Agema 8-12 m IR cameras + visible video
Agema 2 site	Agema 8-12 mm IR camera + visible video
Snoopy site	8-12 mm FTIR spectrometer + visible video
Ram Van	8-12 mm FTIR spectrometer + visible video
Tonka	8-12 mm FTIR spectrometer + gas chromatograph

The Agema 1 site was on the road between McDonald Ranch and Miller's Watch. Agema 2 was deployed on Aerial Cable Road. The Snoopy site was along WSMR Route 13 southwest of the DIPOLE ORBIT 5 structure (the Snoopy spectrometer did not acquire data during the event). Ram Van was located on WSMR Route 7 just northwest of the intersection with Aerial Cable Road. The Ram Van spectrometer followed the cloud for 28.5 minutes.

Before the detonation, the Tonka vehicle maneuvered under the track of a pre-event SF_6 release to obtain an optimum position relative to the DIPOLE ORBIT 5 structure. The position of the Tonka vehicle at shot time was along WSMR Route 13 north of the structure. After the detonation it was directed to the estimated cloud location by cloud tracking operations personnel.

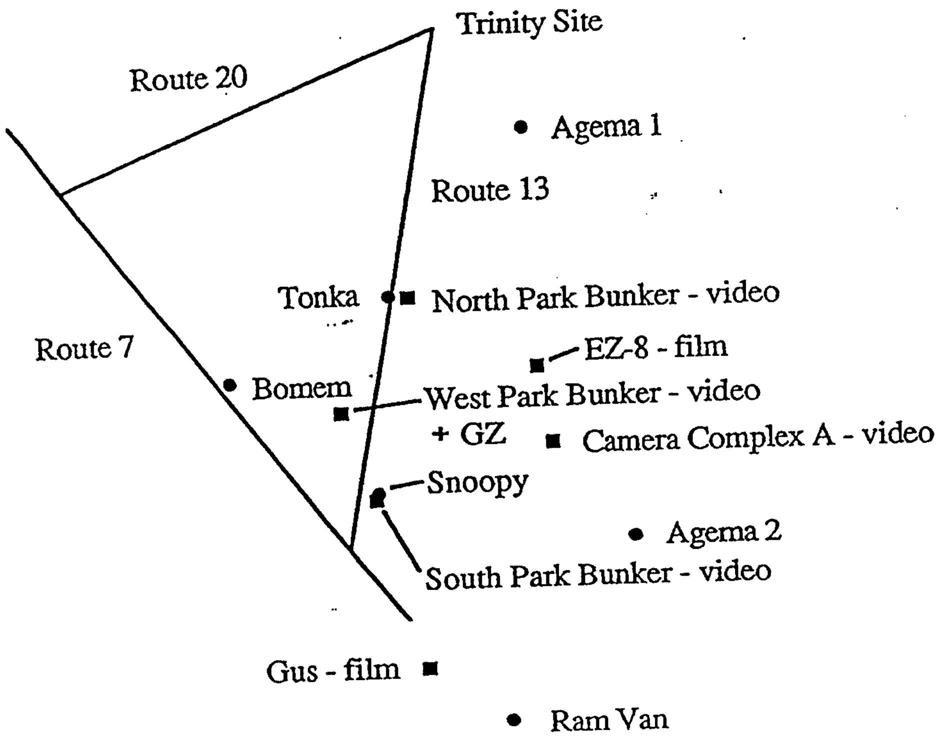

Figure 3-2. Initial stations for the sensor platforms for event DIPOLE ORBIT 5.

The Phillips Laboratory spectrometer tracked the SF_6 cloud:

Bomem	2-12 mm FTIR spectrometer

The Bomem spectrometer was located on WSMR Route 7 about half way between the PHETS administration area and the batch plant. This instrument was used to examine the initial plume and for real-time cloud tracking. It remained at this location throughout the cloud tracking operations.

3.3.2.2 Visible Video. The visible video cameras for post-test determination of the cloud track and dimensions were located at North Park Bunker, South Park Bunker, West Park Bunker, and Camera Complex A for event DIPOLE ORBIT 5 (Figure 3-2). All of these sites were manned. Reduced results were reported for 4.5 min after the detonation (Allen 1996a).

3.3.2.3 Scientific Film Photography. The large format film cameras for post-test determination of the cloud track and dimensions were located at Gus and EZ-8 for event DIPOLE ORBIT 5 (Figure 3-2). These sites were manned; however, the camera at EZ-8 did not function. Reduced results from the single camera were reported for 3.3 min after detonation (Dudziak 1996a).

3.3.2.4 Radiosondes and Other Wind Indicators. The "slow rise" radiosonde was launched from West Park Bunker at 1355 hrs, 18 min after the DIPOLE ORBIT 5 detonation. A second radiosonde for upper air measurements was launched from West Park Bunker at 1443 hrs, 66 min after the detonation. Continuous data were also acquired at the 15 m (50 ft) and 30 m (100 ft) heights on a 30 m (100 ft) tower located near the Air Force 1 structure. The tower data were recorded at 1 min intervals (Davis 1996a).

3.3.2.5 Aerosol Samplers. For event DIPOLE ORBIT 5, 49 Wagner samplers were deployed in an arc from 45 to 360 degrees at ranges from 830 to 1530 m. An additional 48 Wagner samplers were placed in an array 2.06 to 12.38 km from the structure (Larsen 1996b).

3.3.3 DIPOLE EAST 159.

3.3.3.1 Sensors for Tracking Operation. Eight optical sensor platforms were deployed for the DIPOLE EAST 159 event (Table 3-1). The initial stations for the various platforms for this event are shown in Figure 3-3.

The Aerospace Corporation sensor platforms and major instruments all tracked the SF_6 cloud (Herr *et al.* 1997b). All Aerospace platforms except Tonka remained fixed during cloud tracking operations for event DIPOLE EAST 159. The platforms and instruments were:

Agema 1 site	Dual Agema 8-12 mm IR cameras + visible video
Agema 2 site	Agema 8-12 mm IR camera + visible video
Agema 3 site	Agema 8-12 mm IR camera + visible video
Snoopy site	8-12 mm FTIR spectrometer + 3-5 mm IR camera + visible video
Ram Van	8-12 mm FTIR spectrometer + visible video
Tonka	8-12 mm FTIR spectrometer + gas chromatograph

The Agema 1 site was on Aerial Cable Road. Agema 2 was deployed on the road between McDonald Ranch and Miller's Watch. The Agema 3 site was on WSMR Route 7 northwest of the PHETS administration area. Post-event analysis showed that the cloud was detected from the Agema 1 site in only the first image after the detonation. No additional images were obtained from the Agema sites (Herr *et al.* 1997b).

The Snoopy site was along WSMR Route 13 northwest of the Air Force 1 structure. The IR camera was used to measure the roof vent plume temperature for 22 s and to image the cloud. Spectrometer data, including horizontal and vertical scans of the cloud, were obtained from approximately 4 to 14 min after the detonation (Herr *et al.* 1997b).

Ram Van was located at the Beck site. The cloud was never unambiguously identified by the Ram Van spectrometer (Herr *et al.* 1997b).

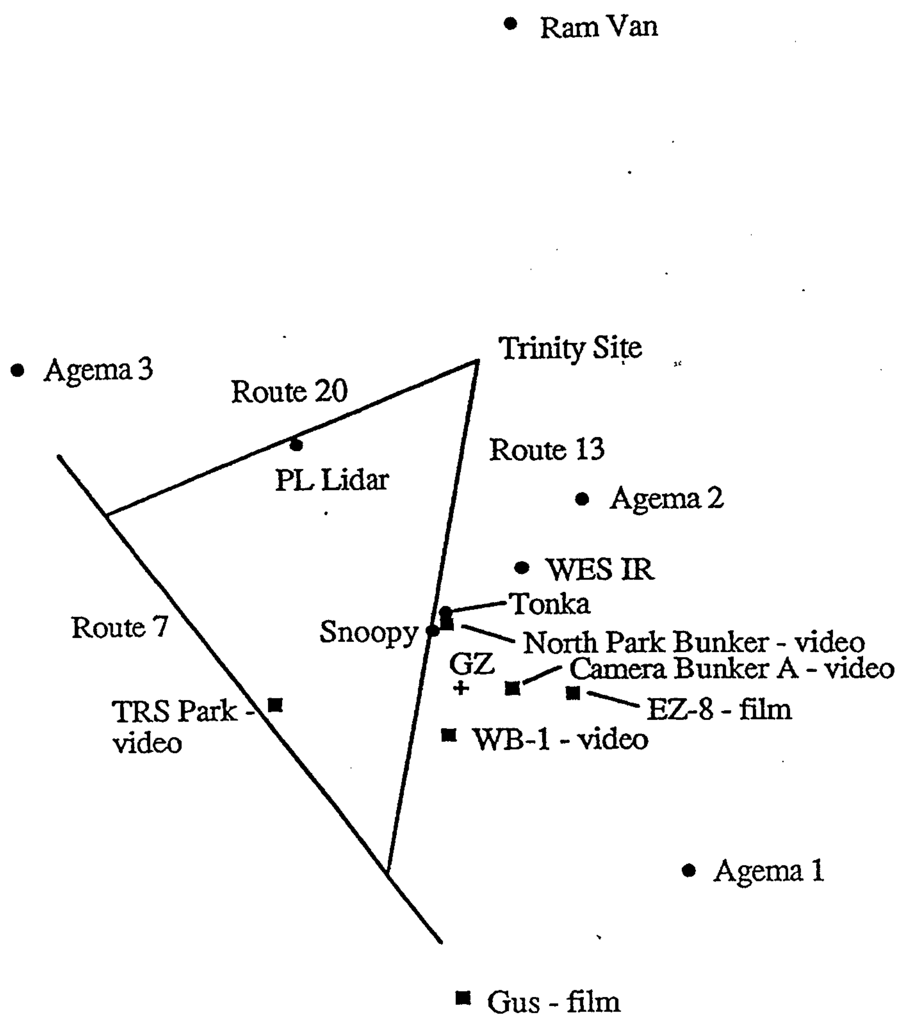

Figure 3-3. Initial stations for the sensor platforms for event DIPOLE EAST 159.

The initial position of the Tonka vehicle was on WSMR Route 13 near North Park Bunker. Tonka detected the cloud on WSMR Route 13, less than 1 km from the Air Force 1 structure, from 6 to 9 minutes after the detonation (Herr *et al.* 1997b).

Only two of the six sensors fielded by The Aerospace Corporation tracked the cloud (Snoopy and Tonka). The failure of the remaining sensors to track the cloud was attributed to destruction of some of the SF_6 in the structure, due to excessive temperatures resulting from combustion of the Bg, and poor IR viewing conditions, generated by high humidity and the presence of clouds (Herr *et al.* 1997b).

The Phillips Laboratory lidar observed the particulate cloud:

PL	10.6 mm CO_2 doppler lidar

The lidar was located on WSMR Route 20 east of the PHETS administration area. It mapped the initial detonation debris distribution but was not able to perform extended cloud tracking (Roadcap *et al.* 1996).

The WES IR camera observed the SF_6 cloud from a location northeast of the Air Force 1 structure:

WES IR	Inframetrics IR camera

3.3.3.2 Visible Video. The visible video cameras for post-test determination of the cloud track and dimensions were located at North Park Bunker, TRS Park, WB-1, and Camera Bunker A for event DIPOLE EAST 159 (Figure 3-3). All of these sites were manned. Reduced results were reported for 3.5 min after the detonation (Allen 1996b).

3.3.3.3 Scientific Film Photography. The large format film cameras for post-test determination of the cloud track and dimensions were located at Gus and EZ-8 for event DIPOLE EAST 159 (Figure 3-3). These sites were manned. Reduced results were reported for 2 min after detonation from the Gus site and 1.3 min from EZ-8 (Dudziak 1996b).

3.3.3.4 Radiosondes and Other Wind Indicators. The "slow rise" radiosonde was launched at 1154 hrs, coincident with the DIPOLE EAST 159 detonation. Continuous data were also acquired at the 15 m (50 ft) and 30 m (100 ft) heights on a 30 m (100 ft) tower located near the structure (Davis 1996a).

3.3.3.5 Aerosol Samplers. During cloud tracking operations for event DIPOLE EAST 159, 15 Wagner samplers were placed in an arc 12 to 18 km north to northeast of the structure and approximately 90 Wagner samplers were placed along and north of US highway 380 north of WSMR (Larsen 1996c).

3.3.4 DIPOLE ORBIT 3.

3.3.4.1 Sensors for Tracking Operations. Five optical sensor platforms were deployed for the DIPOLE ORBIT 3 event (Table 3-1). The initial stations for the various platforms for the DIPOLE ORBIT 3 event are shown in Figure 3-4.

The Aerospace Corporation sensor platforms and major instruments all tracked the SF_6 cloud (Herr *et al.* 1997c). All Aerospace platforms except Tonka remained fixed during cloud tracking operations for event DIPOLE ORBIT 3. The platforms and instruments were:

Agema 1 site	Agema 8-12 mm IR camera + visible video
Agema 2 site	Agema 8-12 mm IR camera + visible video
Agema 3 site	Agema 8-12 mm IR camera + visible video
Ram Van	8-12 mm FTIR spectrometer + visible video
Tonka	8-12 mm FTIR spectrometer + gas chromatograph

The Agema 1 site was on WSMR Route 7 northwest of the PHETS administration area. Agema 2 was deployed on Little Burro Mountain; this site tracked the cloud for 26 min. Agema 3 was located at the Gilmore site southwest of the DIPOLE ORBIT 3 structure. Ram Van was at the Beck site north of the structure. The Ram Van spectrometer monitored the cloud for 31 minutes after the detonation. The initial position of the Tonka vehicle was at the PHETS administration area. Tonka detected the cloud at distances of approximately 7, 33, and 80 km from the

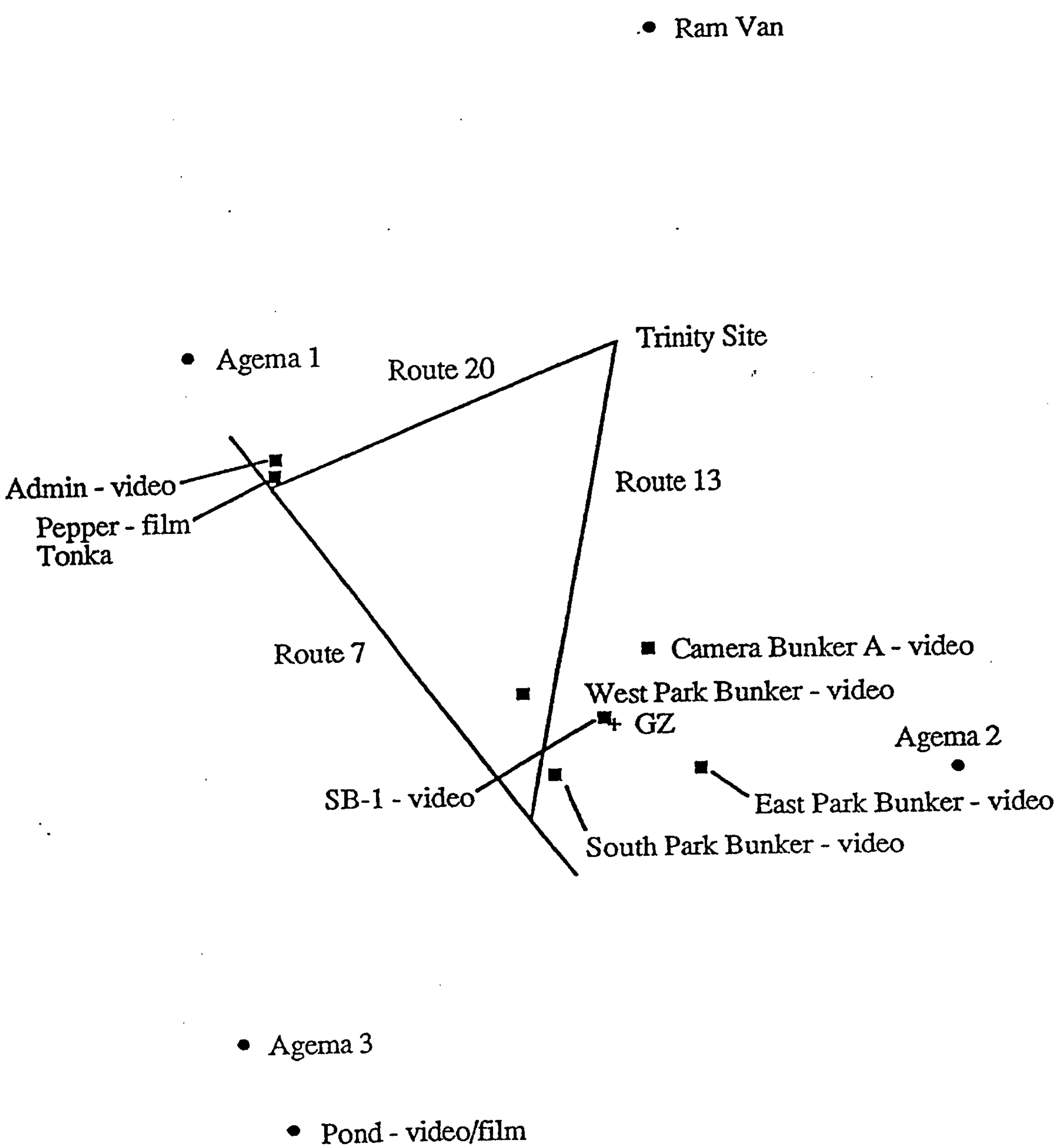

Figure 3-4. Initial stations for the sensor platforms for event DIPOLE ORBIT 3.

structure. Both the spectrometer and the gas chromatograph measured SF_6 at 7 km; only the gas chromatograph obtained data at 33 and 80 km.

3.3.4.2 Visible Video. The visible video cameras for post-test determination of the cloud track and dimensions were located at West Park Bunker, East Park Bunker, South Park Bunker, SB-1, Camera Bunker A, Pond site, and the PHETS administration area for event DIPOLE ORBIT 3 (Figure 3-4). The first 5 sites were unmanned; the last 2 sites were manned. Reduced results were reported for 7 s after the detonation (Allen and Edwards 1997).

3.3.4.3 Scientific Film Photography. The large format film cameras for post-test determination of the cloud track and dimensions were located at the Pond and Pepper sites for event DIPOLE ORBIT 3 (Figure 3-4). These sites were manned. Reduced results were reported for 2 min after the detonation (Dudziak 1997b).

3.3.4.4 Radiosondes and Other Wind Indicators. The "slow rise" radiosonde was launched at 1114 hrs, 22 min after the DIPOLE ORBIT 3 detonation. Atmospheric data were also acquired by the mobile profiler at 30 min intervals (DeRego 1997a).

3.3.4.5 Aerosol Samplers. For event DIPOLE ORBIT 3, 69 Wagner samplers were placed approximately 1000 m from the structure at azimuths from 22.8 to 99.8 degrees. During cloud tracking operations, 40 Wagner samplers were placed at ranges from 6 to 12 km at azimuths from 39.4 to 114 degrees and 6 slit samplers at ranges from 270 to 1210 m at azimuths from 29.5 to 68.3 degrees (Larsen 1997).

3.3.5 DIPOLE ORBIT 6.

3.3.5.1 Sensors for Tracking Operations. Five optical sensor platforms were deployed for the DIPOLE ORBIT 6 event (Table 3-1). The initial stations for the various platforms for the DIPOLE ORBIT 6 event are shown in Figure 3-5.

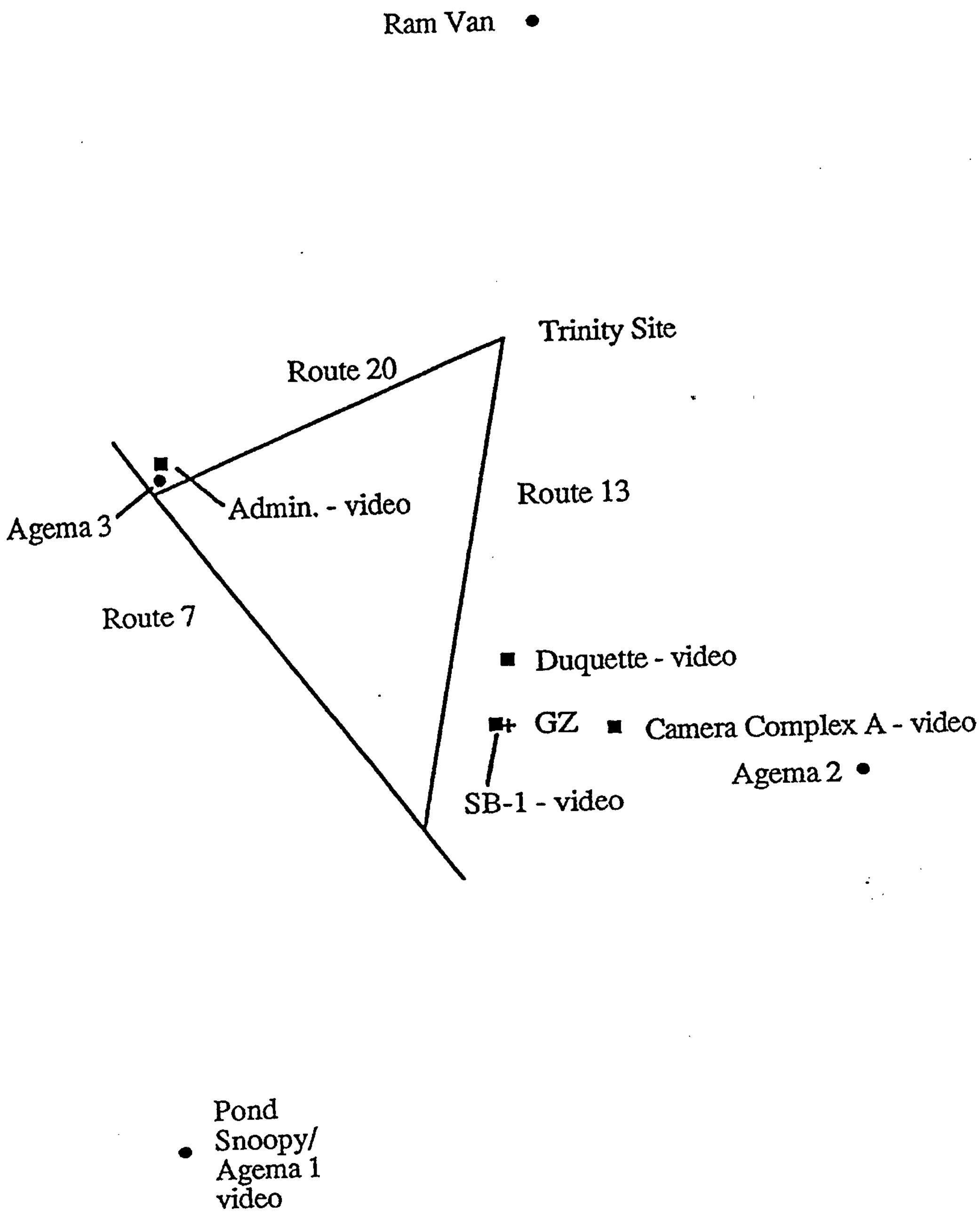

Figure 3-5. Initial stations for the sensor platforms for event DIPOLE ORBIT 6.

The Aerospace Corporation sensor platforms and major instruments all tracked the SF_6 cloud (Herr *et al.* 1997d). All Aerospace platforms except Tonka remained fixed during cloud tracking operations for event DIPOLE ORBIT 6. The platforms and instruments were:

Snoopy/Agema 1 site (TopKick)	8-12 mm FTIR spectrometer + Agema 8-12 mm IR camera + visible video
Agema 2 site	Agema 8-12 mm IR camera + visible video
Agema 3 site	Agema 8-12 mm IR camera + visible video
Ram Van	8-12 mm FTIR spectrometer + visible video
Tonka	8-12 mm FTIR spectrometer + gas chromatograph

The Snoopy/Agema 1 sensors were located at the Pond site. Agema 2 was deployed on Little Burro Mountain. Agema 3 was located at the PHETS administration area. Ram Van was at the Beck site north of the structure. The Ram Van spectrometer monitored the cloud for 53 minutes after the detonation. The initial position of the Tonka vehicle was not reported. Tonka detected the cloud at distances of approximately 30 and 63 km from the structure. Both the spectrometer and the gas chromatograph measured SF_6 at 30 km; only the gas chromatograph obtained data at 63 km.

3.3.5.2 Visible Video. The visible video cameras for post-test determination of the cloud track and dimensions were located at Duquette, Camera Complex A, SB-1, Pond site, and the PHETS administration area for event DIPOLE ORBIT 6 (Figure 3-5). The first 3 sites were unmanned; the last 2 sites were manned. Reduced results were reported for 35 s for this event (Allen and Edwards 1997).

3.3.5.3 Scientific Film Photography. No large format film cameras were fielded for event DIPOLE ORBIT 6.

3.3.5.4 Radiosondes and Other Wind Indicators. The "slow rise" radiosonde was launched at 1120 hrs, 30 min after the DIPOLE ORBIT 3 detonation. Continuous data were also acquired at the 15 m (50 ft) and 30 m (100 ft) heights on a 30 m (100 ft) tower located near the Air Force 1 structure. The tower data were recorded at 1 min intervals. Atmospheric data were also acquired by the mobile profiler at 30 min intervals (DeRego 1997b).

SECTION 4
RESULTS

4.1 DIPOLE ORBIT 1.

4.1.1 Real-Time Cloud Tracking.

The real-time cloud positions generated manually during cloud tracking operations for event DIPOLE ORBIT 1 are shown by the solid circle symbols in Figure 4-1. The coordinates are distances from the structure, with positive X to the east of the structure and positive Y to the north of the structure. The cloud was tracked by triangulation of two or more azimuths for 75 min after the detonation.

The Ram Van spectrometer continued to observe the cloud until 90 min after the detonation. No additional sensors were able to provide azimuths to the cloud after 75 min to determine cloud positions by triangulation.

The XM94-1 lidar also produced a real-time track (from 5 to 35 min after the detonation) since it provided both azimuth and range to the cloud centroid from its position on the test bed (the azimuth information was included in the combined real-time track determined using all sensors). We determined the XM94-1 real-time track using the lidar locations and centroid data given by Hungate *et al.* (1997). This track is shown by the diamond symbols in Figure 4-1.

The azimuths and ranges for the two real-time tracks were not in good agreement. There was a difference of 900 m in the location of the XM94-1 lidar in the north-south direction as given by Hungate *et al.* (1997) and Hawks (1997). Any effects of this disagreement on the results shown in Figure 4-1 are unknown.

The Tonka vehicle was directed by cloud-track operations. It obtained its primary spectroscopic

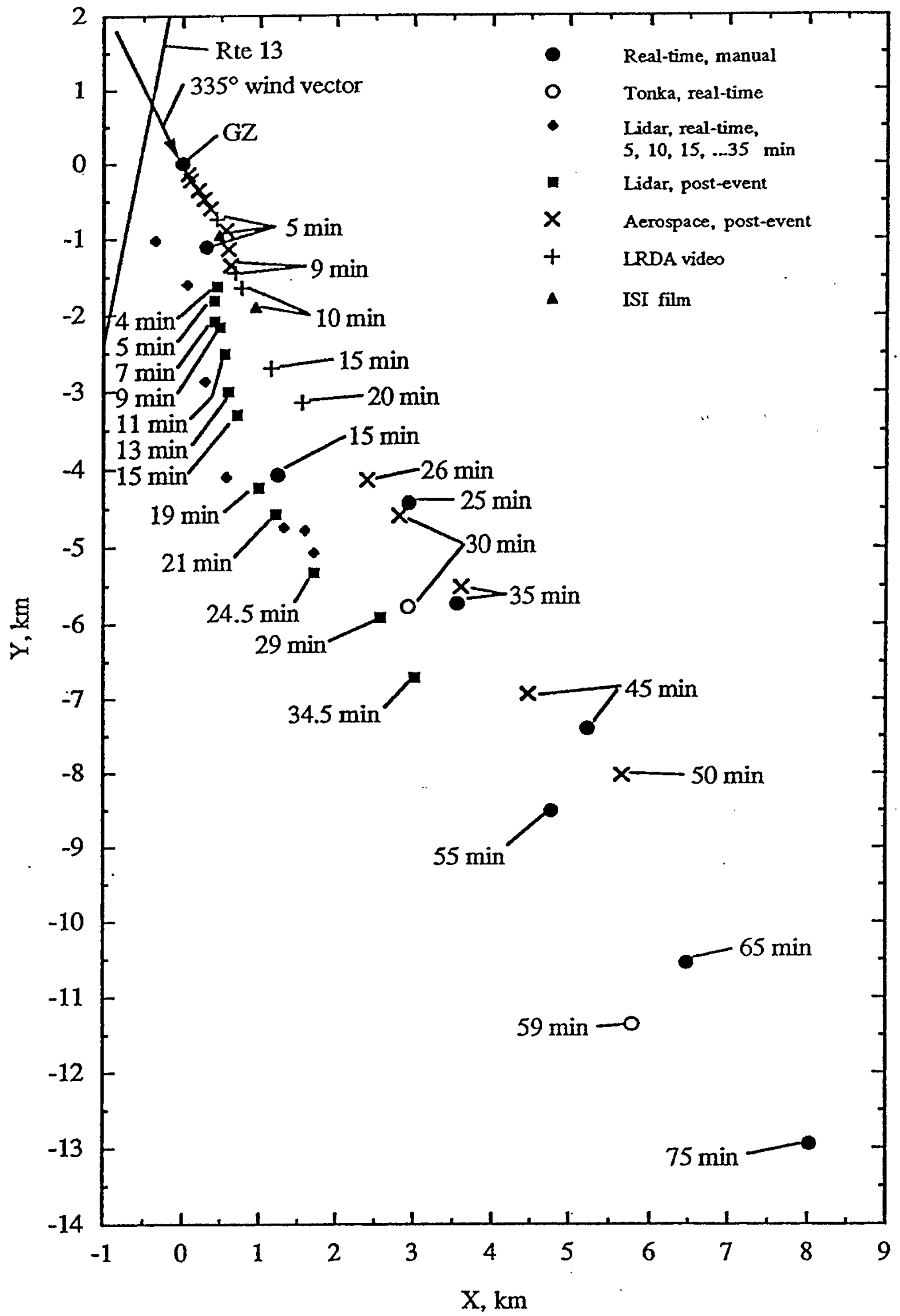

Figure 4-1. DIPOLE ORBIT 1 cloud track results.

data set for event DIPOLE ORBIT 1 while positioned near the intersection of WSMR Route 7 and Aerial Cable Road. The cloud passed over the vehicle between 23 and 52 min after the detonation (the location is shown by the open circle symbol labeled 30 min in Figure 4-1). The Tonka sensors measured the cloud at one additional location, south of Mockingbird Gap (just south of the intersection of WSMR Routes 7 and 12) at 59 min after the detonation.

4.1.2 Post-Event Analyses.

4.1.2.1 Cloud Track. The Aerospace Corporation conducted a post-event analysis of the cloud tracking results for their sensors for times from 1 to 50 min after the detonation (Hall 1997). Information from the 522 and Snoopy sites was used from 0 to 9 min and from the 522 site and the Ram Van for the later times. The criterion for sensor selection was that the entire cloud was in the field of view of the sensor so that the edges of the cloud could be discerned. The images overfilled the fields of view of the sensors between 9 and 26 min, so that no information was provided for this time period. As mentioned in Section 4.1.1 the Ram Van spectrometer continued to track the cloud to 90 min after the detonation, but no other azimuths were available for triangulation. The post-event Aerospace track is shown by the x symbols in Figure 4-1.

The cloud track from the XM94-1 lidar was also analyzed post-event (Hungate *et al.* 1997). This track is shown by the square symbols in Figure 4-1. For times up to 20 min the azimuths all shifted toward the east and the ranges were greater. At the later times, the azimuths did not change but the ranges became significantly greater. Hungate *et al.* (1977) did not discuss the differences between the real-time and post-event results.

Logicon RDA (LRDA, Allen and Ball 1997) produced a cloud track from the analysis of the visible video records for 20 min after the detonation. The results shown were obtained by triangulation from the camera locations at the North Park Bunker and EZ-8 sites (+ symbols in Figure 4-1).

Information Science, Inc. (ISI, Dudziak 1997a) obtained a cloud track from the analysis of the large format film records for 10.5 min after the detonation. These results were obtained from cameras located at the South Park Bunker and the EZ-8 site (triangle symbols in Figure 4-1).

Overall, Figure 4-1 shows that the post-event tracks determined by Aerospace, Logicon RDA, and ISI were consistent with each other and in reasonable agreement with the predominant wind vector at shot time (see Section 4.1.2.3). The lidar results indicated a more southerly track. After 20 min all of the cloud positions except the real-time lidar track (which was substantially revised post-event) were within approximately one cloud width of each other (see Section 4.1.2.2).

4.1.2.2 Cloud Dimensions. The Aerospace Corporation determined cloud height as a function of time. Figure 4-2 gives the Aerospace results for 34 min after the detonation (x symbols). For the first 2 min, the height is that of the higher of two clouds observed (the cloud from the door rose faster than that from the rear of the structure). From 3 to 10 min, heights are given for the cloud top, center, and bottom. At later times, heights are given for the cloud top and the peak column density. The reference height for Figure 4-2 was the altitude of the ground level at the structure, 1490 m MSL.

Logicon RDA (Allen and Ball 1997) determined the cloud top height from the visible video records for 20 min after the detonation using the cameras located at Camera Bunker B and EZ-8 for the first 5.5 min and at North Park Bunker and EZ-8 from 5.5 to 20 min. These results are given by the + symbols in Figure 4-2.

ISI (Dudziak 1997) reported cloud top heights from the large format film records (South Park Bunker and EZ-8 locations) for 10.5 min after the detonation. These results are given by the triangle symbols in Figure 4-2.

The cloud top height results for all of the sensors were in good agreement until 10 min after the detonation. This agreement for the visible (dust) and IR (SF_6) clouds indicates that the solid and gaseous tracers were well mixed for this event. After about 10 min the visible cloud became

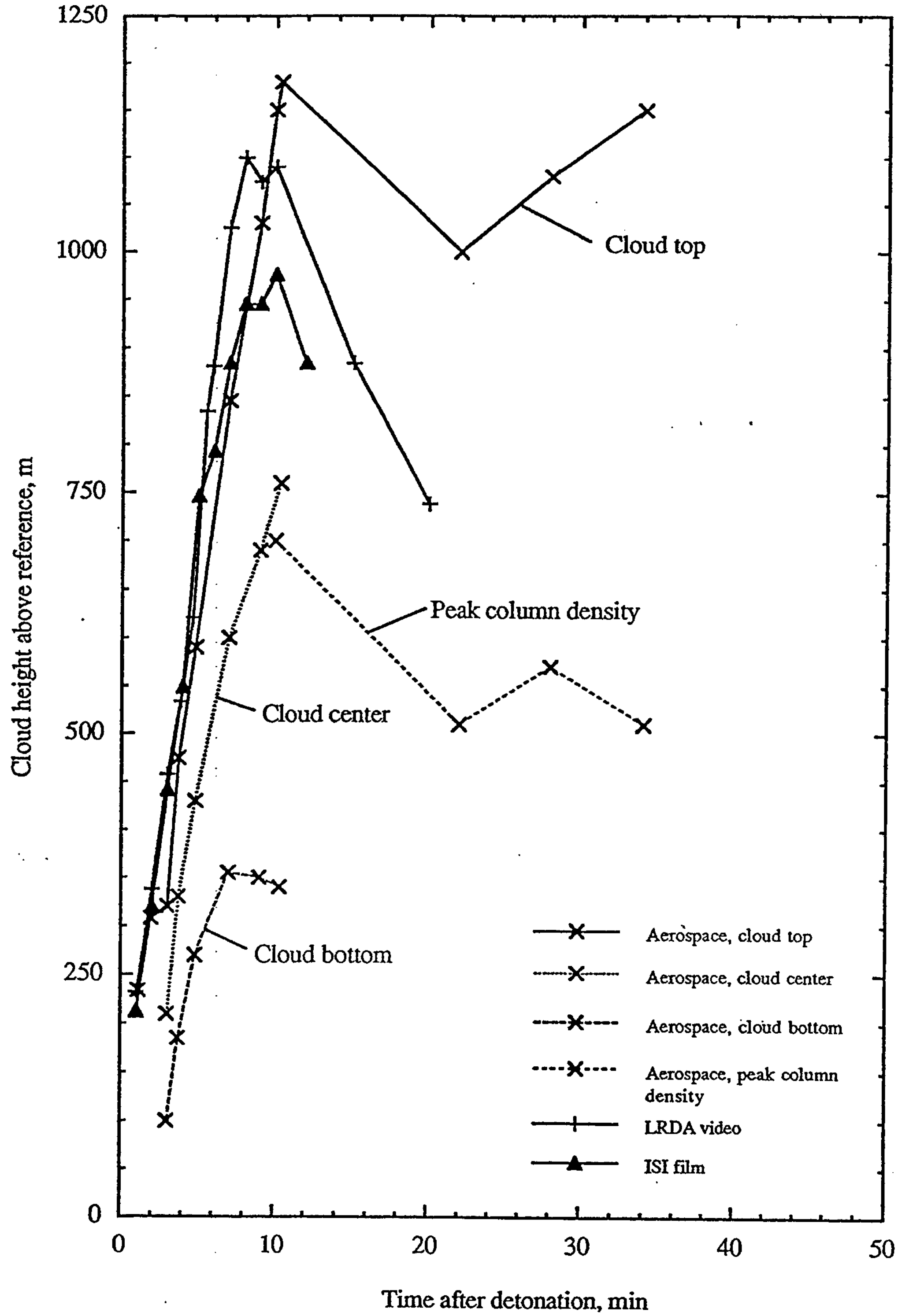

Figure 4-2. DIPOLE ORBIT 1 cloud heights.

rather indistinct and the visible sensors (video and film cameras) lost their ability to resolve the top of the cloud. This resulted in rapid decreases in observed cloud top height.

Cloud widths were determined by Aerospace, Logicon RDA, and ISI. Figure 4-3 presents these results using the same symbols as Figure 4-2. The Aerospace results were obtained for the Snoopy, 522 site, and Ram Van sensors as indicated. The Logicon RDA results were obtained for two sensor pairs, south/east and north/east. The cloud widths depended on the viewing directions since the cloud was irregular in shape. For the first 2 min after the detonation the cloud was aligned with the symmetry axis of the structure. After about 7 min the cloud tended to stretch out in the direction of downwind motion. Intermediate times were in a transition period (Hall 1997). The cloud also became less distinct at later times and eventually became invisible to the visible video and film cameras.

The XM94-1 lidar also determined the extents of the cloud along and perpendicular to the line of sight of the lidar (Hungate *et al.* 1997, post-event analysis). These results are also shown in Figure 4-3 (square symbols).

Except for the Logicon RDA results for the south/east sites, which were probably affected by the cloud passing directly over the south site at 5.5 min after the detonation, the results for all sensors were in good agreement for the first 10 min after the detonation. The visible sensors indicated incorrect decreases in cloud width as they became unable to identify the edges of the cloud beyond 10 min. The results for the IR and lidar sensors were in reasonable agreement at the later times.

<u>4.1.2.3 Meteorological Observations</u>. The weather on shot day for DIPOLE ORBIT 1 was clear and mild with light northerly to northwesterly winds following a cold front that had passed through the area the night before (Jameson 1997). The "slow rise" radiosonde, launched from West Park at shot time, provided meteorological conditions from the surface to an altitude of approximately 6900 m MSL (the surface altitude at the launch site was 1483 m MSL). Figure

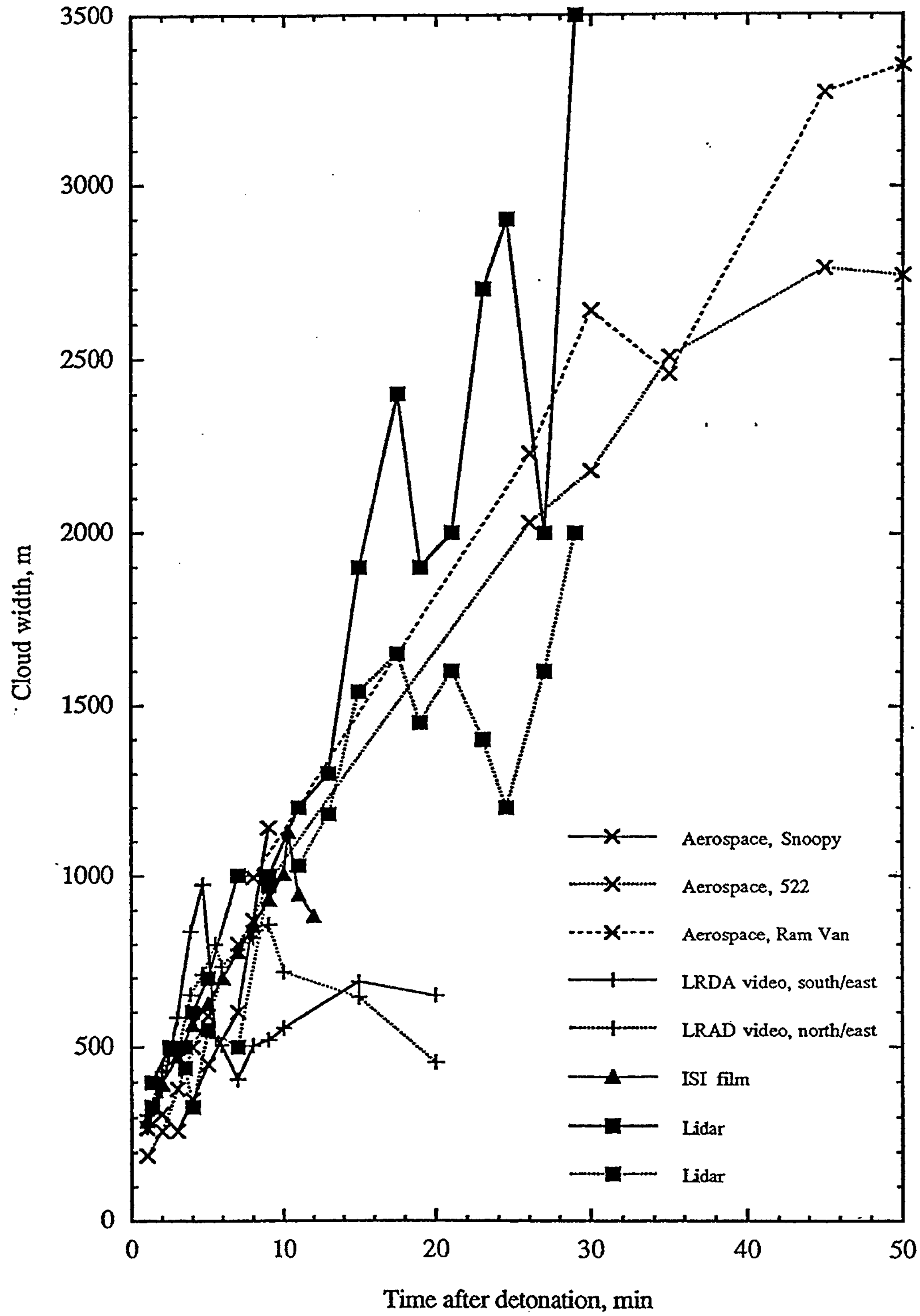

Figure 4-3. DIPOLE ORBIT 1 cloud widths.

4-4 gives the wind direction versus altitude. The balloon rose somewhat slower than the top of the cloud until about 11-12 min after the detonation when the cloud growth slowed. The wind was from 335+10 deg at the altitudes of the middle to the top of the cloud. As shown in Figure 4-1, the cloud tracks followed this wind direction (except for the lidar tracks prior to 15 min after the detonation).

Figure 4-5 gives the wind speed versus altitude. The wind speeds were low near the surface (2-3 m/s) and increased to 5 m/s at 2200 m MSL. The translation speed of the cloud determined post-event by Aerospace was 2-3 m/s for the first 9 min after the detonation, increasing to approximately 4 m/s after about 30 min (Hall 1997).

Figure 4-6 gives the air temperature versus altitude. The inversion at about 3300 m MSL could have been responsible for stabilization of the cloud just below 2700 m MSL (using the Aerospace cloud heights).

4.1.2.4 <u>Taggant Gas Results</u>. The Aerospace Corporation sidelooking spectrometers (Snoopy and Ram Van) measured the SF_6 column density in the cloud as a function of position within the cloud and time (Hall 1997). The peak column density at 5 min after the detonation was 130 parts-per-million meters (ppm-m). This decreased to 64 ppm-m at 10 min and 6.7 ppm-m at 30 min.

The uplooking spectrometer in the Tonka vehicle measured a maximum vertical SF_6 column density of 2.3 ppm-m at 30 min after the detonation. The peak SF_6 concentration at ground level measured by the gas chromatograph was approximately 2.3 parts-per-billion (ppb) (Hall 1997). The peak ground level concentration at 59 min after the detonation was about 0.2 ppb.

Aerospace estimated the total SF_6 mass in the cloud by integrating the column density (converted to kg/m^2) over the entire cloud (the method is described in detail by Hall 1997). Using data from the Ram Van spectrometer, a mass of 36 kg (80 lb) of the original 91 kg (200 lb) of SF_6 was obtained at 26.25 min after the detonation. Using data from both the Ram Van and Tonka

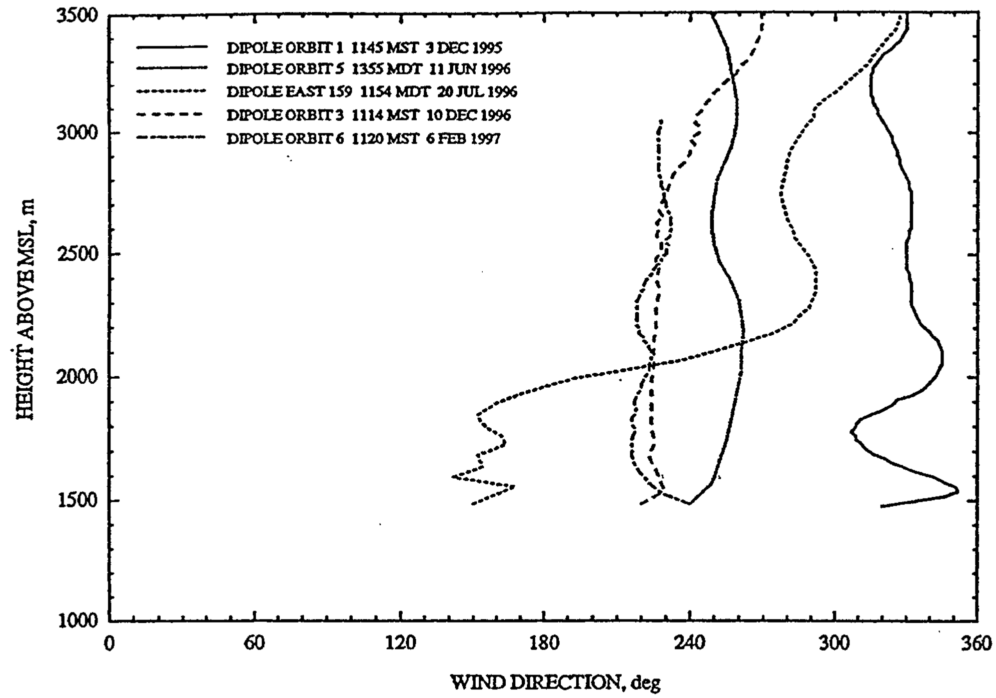

Figure 4-4. Wind directions at West Park.

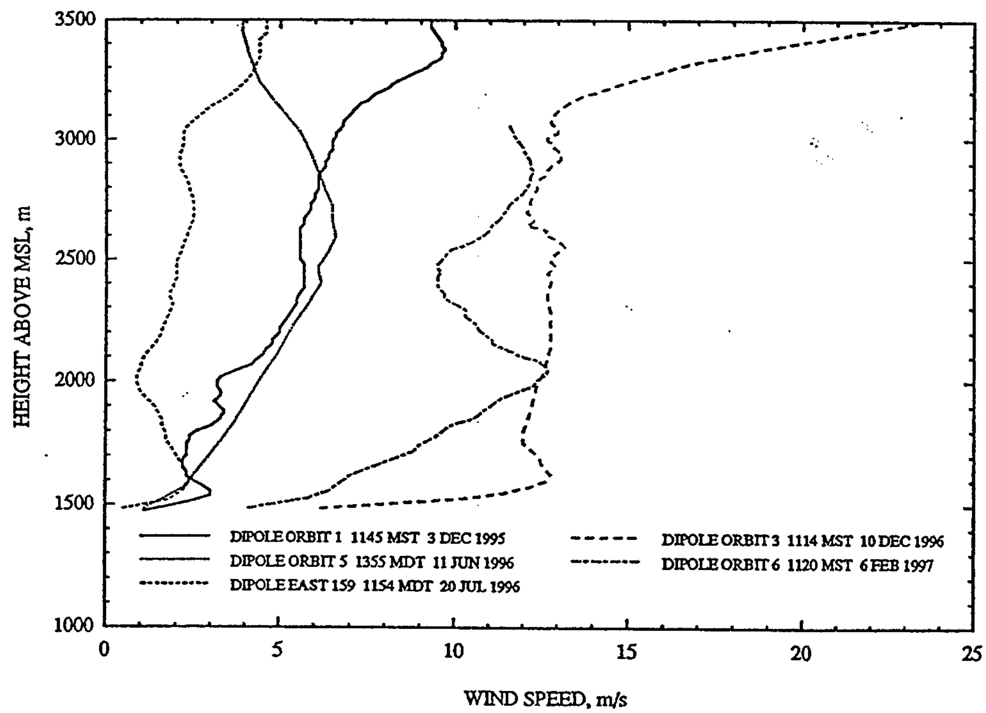

Figure 4-5. Wind speeds at West Park.

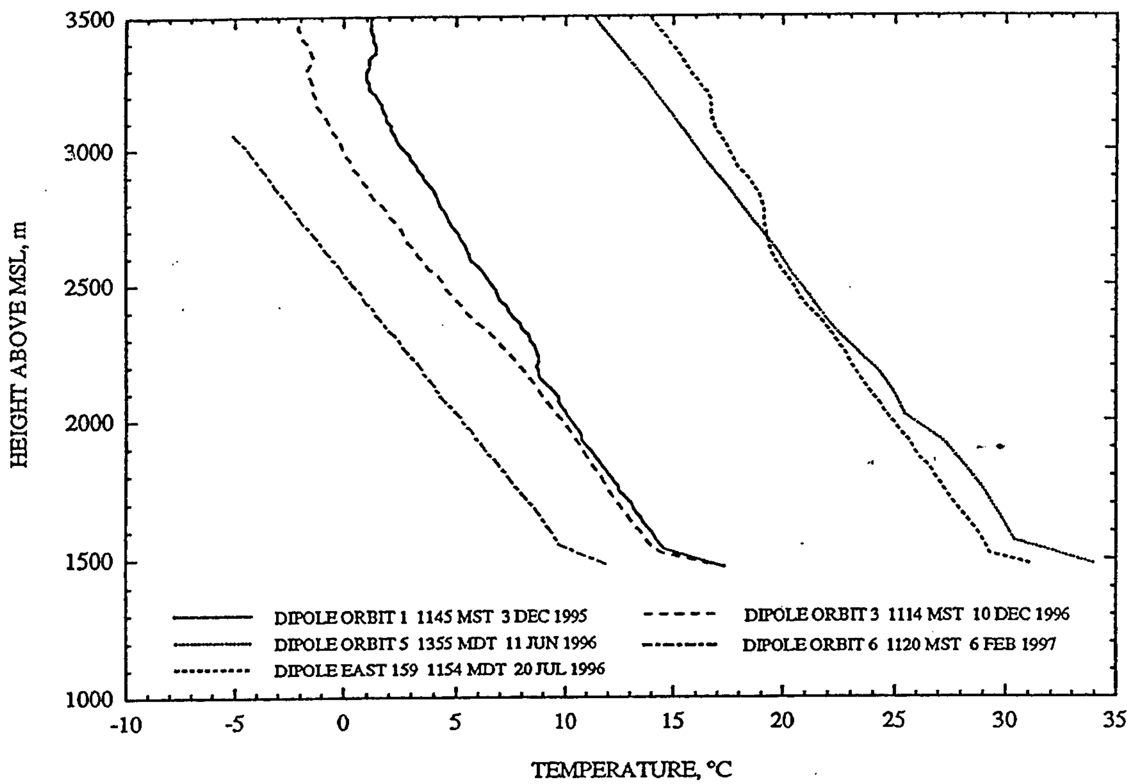

Figure 4-6. Air temperatures at West Park.

spectrometers, a mass of 30 kg (66 lb) was obtained. The error bounds on these results were estimated at +50% (Hall 1997).

Both SF_6 and CF_4 were used as taggants for event DIPOLE ORBIT 1. Due to the lower thermal stability of SF_6, comparison of the SF_6/CF_4 ratio measured in the detonation cloud to that of the gases installed in the structure can give an indication of the temperature attained in the structure during the event. Aerospace measured these ratios (the ratio for the cloud was obtained using the Tonka uplooking spectrometer) and determined that, within the measurement uncertainties, no thermal decomposition of the taggant gases occurred for this event (Hall 1997).

4.1.3 Ground Sampling.

Aerosol samplers were placed on the ground at ranges from the DIPOLE ORBIT 1 structure of approximately 910 m, 27.8 km, and 57.7 km (Larsen 1996a). The samplers were active for the following time intervals relative to the detonation time: 910 m, T-108 min to T+92 min; 27.8 km, T+49 min to T+133 min; and 57.7 km, T+205 min to T+370 min. For the 910-m sample line, the maximum number of Bg colony forming units (CFU) was obtained at an azimuth of 169 deg (40,000/sample). The maximum CFU count for Bt/other (600/sample) occurred at an azimuth of 152 deg (other refers to other bacteria that were indistinguishable from Bt). Positive CFU counts were obtained for either Bg or Bt throughout the azimuth range of the samplers (128 to 190 deg). Figure 4-7 shows the sampler locations with positive CFU counts (dark line).

At the 27.8 km range significant Bg counts (> 100/sample) occurred at 9 azimuths which were scattered over the sampler array (azimuths 119 to 153 deg). Lower CFU counts occurred at 28 additional azimuths. Positive CFU counts for Bt/other were less numerous but also occurred throughout most of the sampler array. No Bg or Bt was observed for azimuths from approximately 130 to 139 deg. The dark lines in Figure 4-7 show the sampler locations with positive CFU counts. Samplers located in the open region between the dark lines had zero counts.

At the 57.7 km range positive Bg and Bt/other CFU counts occurred at 5 azimuths (Figure 4-7). The locations of the samplers with zero counts were not available.

Roving samples were obtained at 11 locations. The locations with positive Bg and/or Bt/other CFU counts are shown by the solid triangle symbols in Figure 4-7. Locations with zero CFU counts are shown by the open triangle symbols. The positive and zero CFU counts for the rover samples were in general agreement with those obtained from the other samplers.

The material recovered from the ground samplers was analyzed for the rare earth tracers incorporated into the Bg and Bt mixes (Mason and Finnegan 1997a). Significant levels of indium and dysprosium were found in many of the analyzed samples. The correlation between these tracers and the Bg and Bt counts was good at the 910-m and 27.8-km ranges and poor at the 57.7 km range (the azimuths cited by Mason and Finnegan 1997a appear to be in error).

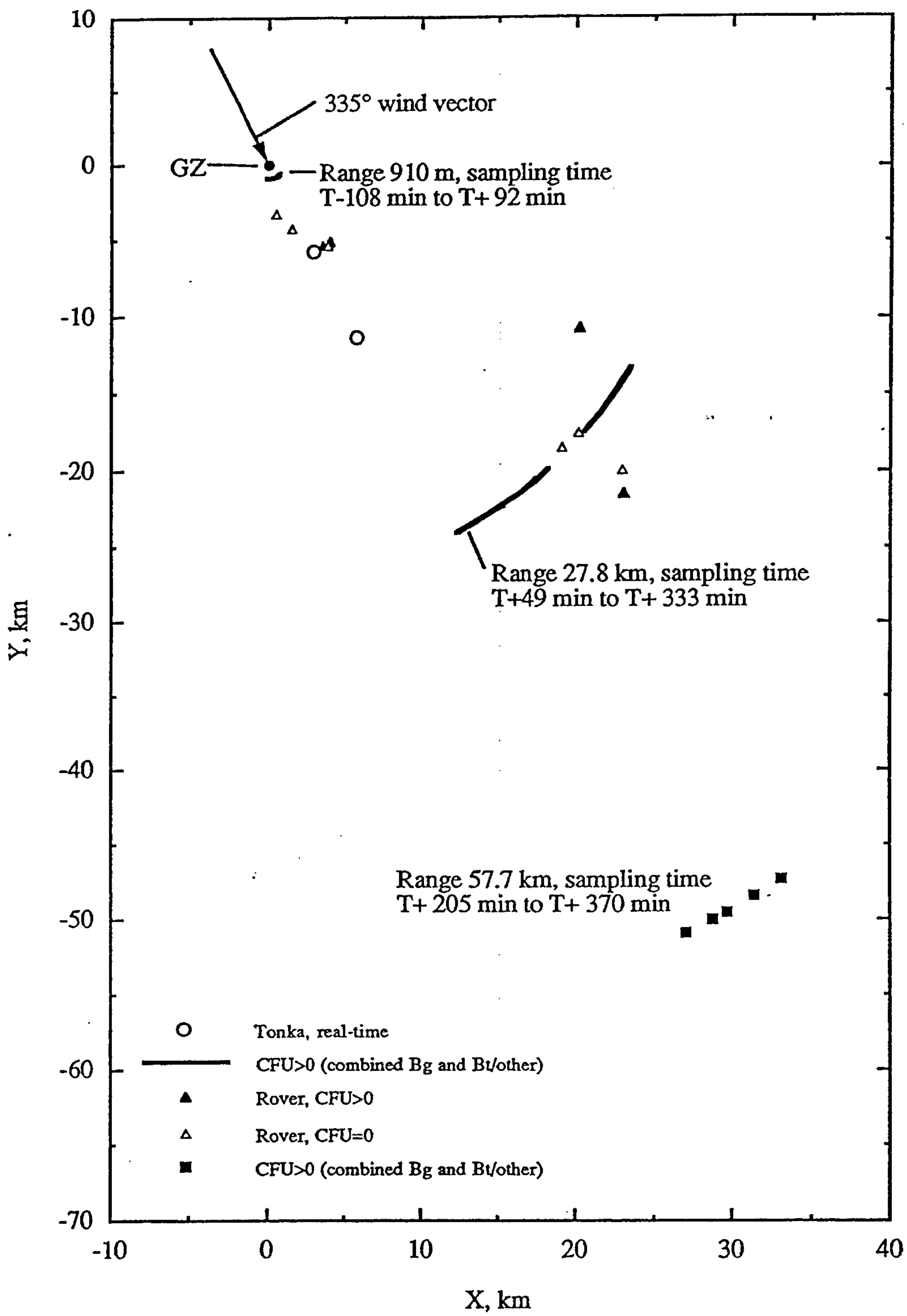

Figure 4-7. DIPOLE ORBIT 1 ground sampling results.

4.1.4 Discussion.

The DIPOLE ORBIT 1 cloud followed the prevailing winds, as determined by the "slow rise" radiosonde, across flat terrain and then through Mockingbird Gap. The real-time cloud tracking operations produced triangulated cloud positions that were validated by post-event analysis for 75 min after the DIPOLE ORBIT 1 detonation. The cloud range from the structure was approximately 15 km at this time (Figure 4-1). The Tonka vehicle was successfully directed to positions where it intercepted the cloud at 30 min and 59 min after the detonation (times of peak cloud density) at ranges of 6.5 and 13 km.

The Ram Van spectrometer continued to provide cloud azimuth data to a total time of 90 min after the detonation and an approximate range of 20 km; however, additional sensors were not available to triangulate on cloud position. By this time the cloud was south of Mockingbird Gap. Possible additional cloud intercepts by sensors which were relocated south of Mockingbird Gap could not be confirmed by post-event analysis. It appeared that the instrument operators had better ability to discern a very weak IR signal in real time than could be gleaned from the recorded data during the post-event analysis, so it is possible that some of the later time cloud intercepts were indeed real.

The IR sensors, tracking the SF_6 cloud, provided triangulated results for cloud position and dimensions for 2-3 times as long as the visible sensors (video and film cameras), which tracked the visible (dust) cloud. If additional sensors had been positioned south of Mockingbird Gap to intercept the cloud, the IR sensors could have tracked the cloud 4-5 times as long as the visible sensors.

The lidars demonstrated their ability to obtain cloud azimuths, ranges, and dimensions independent of the optical sensors. The cloud track from the XM94-1 lidar was not in good agreement with the track obtained by triangulation using the azimuths from multiple sensors (this could have resulted from the use of an incorrect location for the lidar or the lidar could have viewed a different region of the cloud than observed by the other sensors).

Cloud tracking operations personnel were able to extrapolate the direction and speed of cloud travel sufficiently accurately to permit the capture of ground samples at ranges of 28 and 58 km, well beyond the range of the real-time cloud track. Figure 4-7 compares the ground sampler results to the Tonka cloud intercept locations at 30 and 59 min after the detonation for event DIPOLE ORBIT 1. The azimuths for peak CFUs at the 910-m range (152 and 169 deg) were approximately in line with the wind vector (155 deg when converted to azimuth angle). Many samplers were clearly in the path of the detonation cloud at the appropriate times after detonation.

Since positive CFU counts were obtained for some ground samplers over the entire arcs of samplers, the edges of the cloud could not be determined from the ground sampling results. This effectively limited the definition of the cloud widths to 50 min after the detonation, as obtained from the IR observations (Figure 4-3). The cloud centroid was approximately 12 km from the structure at this time (Figure 4-1).

4.2 DIPOLE ORBIT 5.

4.2.1 Real-Time Cloud Tracking.

The manually generated real-time cloud positions at 10, 20, and 30 min after the DIPOLE ORBIT 5 detonation are shown in Figure 4-8 (solid circle symbols). The cloud motion was toward the east but was not well defined.

The Tonka vehicle detected the cloud 0.76 km northeast of the structure at 7 min after the detonation (Herr *et al.* 1997a). The Tonka vehicle position at this time after the detonation is shown in Figure 4-8 (open circle symbol). Additional cloud intercepts occurred at 13, 16, 24, 30, and 63 min after the detonation while the Tonka vehicle was proceeding east toward Oscura Gap. The final intercept (at 63 min) was approximately 8 km east of the structure.

4.2.2 Post-Event Analyses.

4.2.2.1 Cloud Track. The Aerospace Corporation conducted a post-event analysis of the cloud tracking results for their sensors for times from 1 to 10 min after the detonation (Herr *et al.* 1997a). Information from Agema 1, Agema 2, and the Ram Van sensors was used to define elliptical cloud footprints on the ground at times after the detonation of 4 and 9 min. The centers of the elliptical footprints determined by Aerospace (scaled from Herr *et al.* 1997a) are shown in Figure 4-8. The Ram Van spectrometer followed the cloud for 28.5 min; however, no other sensor could follow the cloud beyond 10 min, so no further triangulation for cloud position was possible.

Logicon RDA (Allen 1996a) analyzed the visible video records for 4.5 min after the detonation. The results shown by the + symbols in Figure 4-8 were obtained by triangulation from the camera locations at North Park Bunker and West Park Bunker. These results show that the cloud initially moved toward the south.

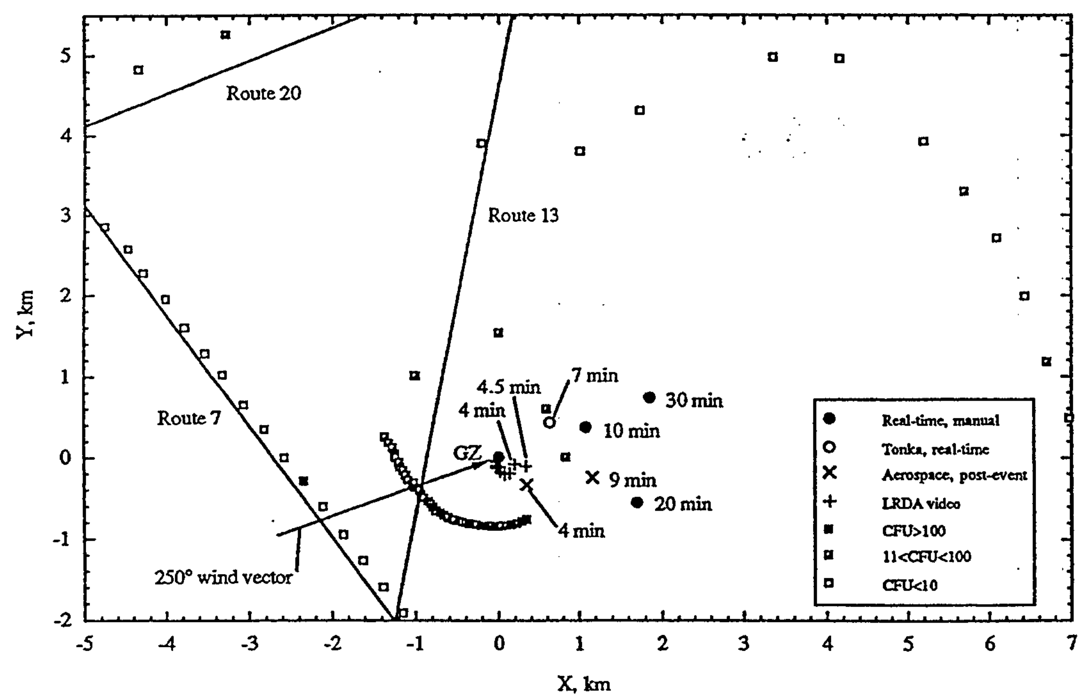

Figure 4-8. DIPOLE ORBIT 5 cloud track and ground sampling results.

As a result of the failure of the large format film camera at EZ-8, ISI (Dudziak 1996a) was unable to obtain a cloud track for event DIPOLE ORBIT 5. Dudziak reported that the cloud was about 160 m south of the structure at 3.3 min after the detonation.

The cloud positions determined by Logicon RDA were in reasonable agreement with the 4 min location obtained by post-event analysis of the IR data by Aerospace for event DIPOLE ORBIT 5. The slow eastward motion of the cloud indicated by the real-time track was confirmed by the Tonka intercepts.

4.2.2.2 Cloud Dimensions. The Aerospace Corporation determined the cloud top height as a function of time from data acquired by the Agema 1 and Agema 2 sensors. Figure 4-9 gives the Aerospace results for 10 min after the detonation (x symbols).

Logicon RDA (Allen 1996a) determined the cloud top height from the visible video records for 4.5 min after the detonation using the cameras pairs located at Camera Complex C/West Park Bunker and South Park Bunker/West Park Bunker. These results are shown in Figure 4-9 (+ symbols).

ISI (Dudziak 1997) reported cloud top heights from the large format film records at South Park Bunker for 2.3 min after the detonation. These results are given by the triangle symbols in Figure 4-9.

Comparison of the visible (dust) cloud with the IR (SF_6) cloud indicates that the visible cloud was much higher. It is possible that the SF_6 was released from the structure later than the dust cloud. No comparisons were possible beyond 4.5 min since the visible cloud was rapidly dissipating at that time.

Cloud widths were determined by Aerospace (scaled from Herr *et al.* 1997a), Logicon RDA, and ISI. Figure 4-10 presents these results using the same symbols as Figure 4-9).

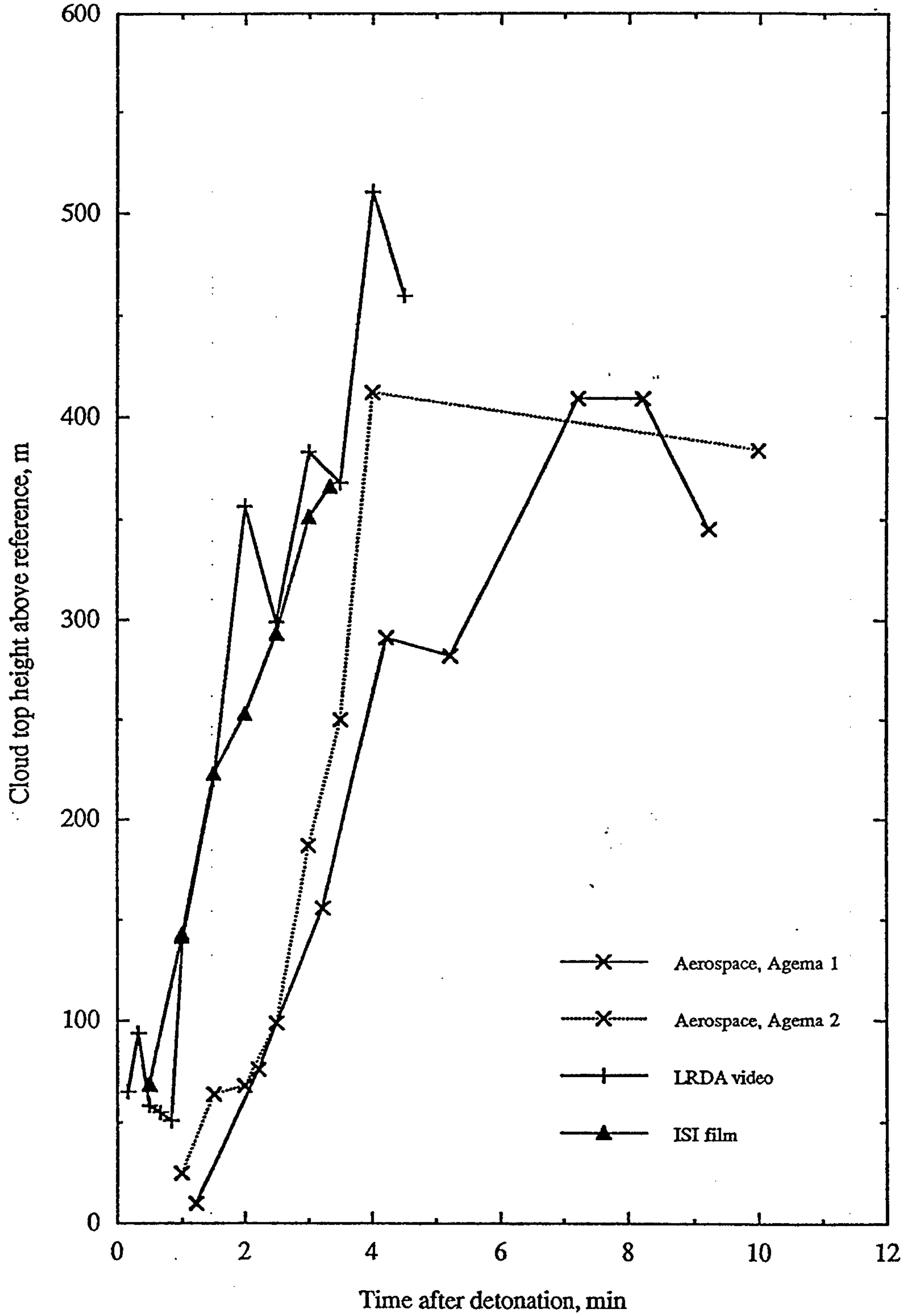

Figure 4-9. DIPOLE ORBIT 5 cloud heights.

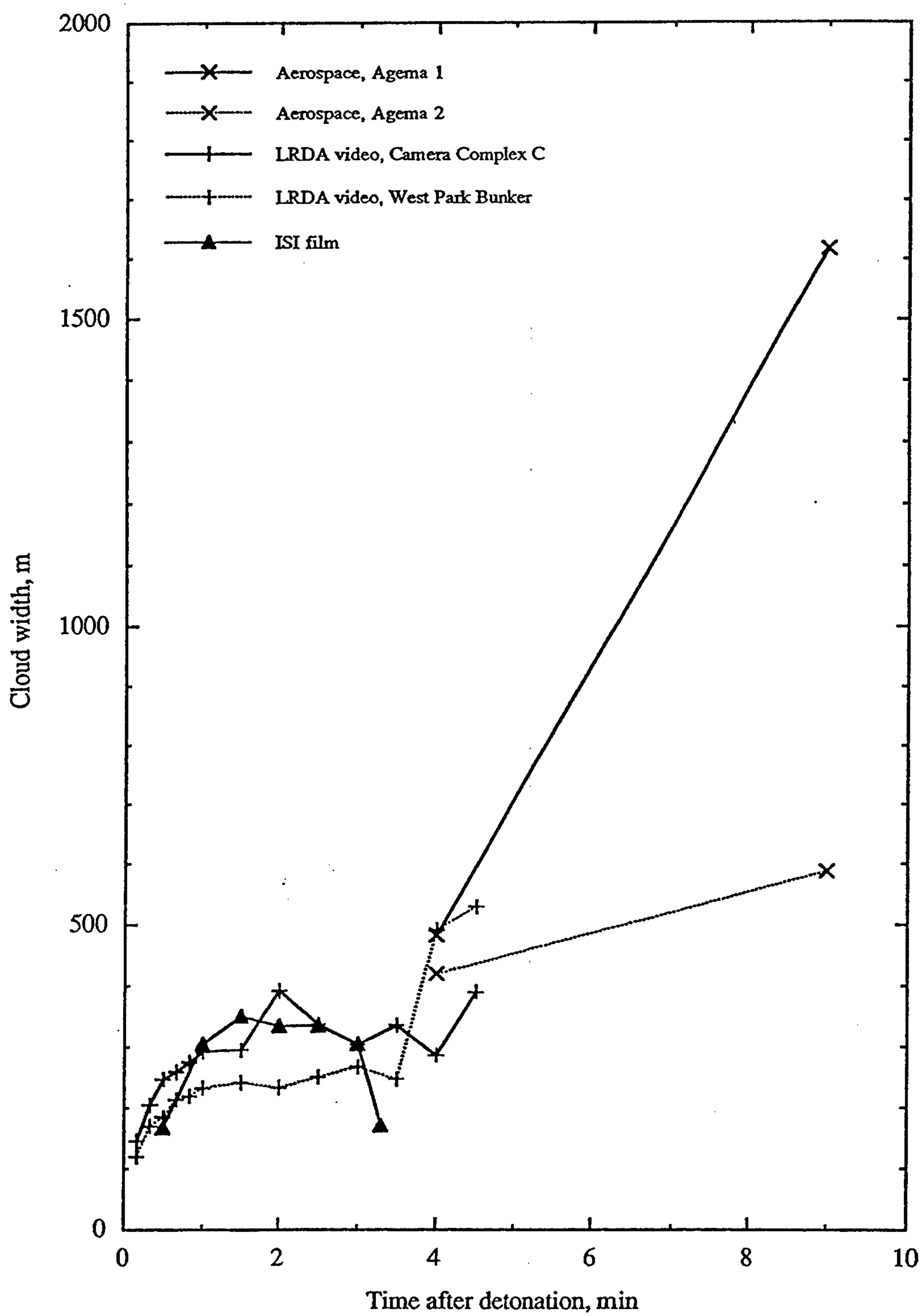

Figure 4-10. DIPOLE ORBIT 5 cloud widths.

The cloud widths determined from the video and film analyses were the only results available prior to 4 min after the detonation. These results were in good agreement with those obtained from the Aerospace data at that time. The Aerospace results indicate substantial downwind stretching of the cloud by 9 min after the detonation.

4.2.2.3 Meteorological Observations. The weather on shot day for event DIPOLE ORBIT 5 was hot and dry. The radiosonde was launched from West Park 18 min after the detonation, after many of the sensors had ceased tracking the cloud. This sensor provided meteorological conditions from the surface to an altitude of approximately 4800 m MSL. Figure 4-4 gives the wind direction versus altitude. The wind was from 250+10 deg from the surface to about 3600 m MSL, which was well above the maximum cloud top altitude. At the tower located near the Air Force 1 structure, the wind direction at the detonation time was from 200 deg (Jameson 1996a). By 10 min after the detonation, the wind direction at the tower had changed to 320 deg. The variable nature of the wind probably contributed to the uncertainty in the cloud track and the rapid dispersion of the cloud. Figure 4-5 gives the wind speed versus altitude. The wind speeds were low near the surface (1-3 m/s) and increased to about 5 m/s at 2100 m MSL, near the cloud top.

Figure 4-6 gives the air temperature versus altitude. No inversions were present.

4.2.2.4 Taggant Gas Results. The Aerospace Corporation sidelooking spectrometer in the Ram Van measured the SF_6 column density in the cloud as a function of position, azimuth angle, and time (Herr *et al.* 1997a). The peak measured column density was approximately 10 ppm-m.

The uplooking spectrometer in the Tonka vehicle measured a maximum vertical SF_6 column density of 5.7 ppm-m at 7 min after the detonation. The peak SF_6 concentration at ground level measured by the gas chromatograph was approximately 31 ppb, measured 9 min after the detonation (Herr *et al.* 1997a). The peak ground level concentration at 63 min after the detonation was 87 parts-per-trillion (ppt).

Aerospace measured the SF_6/CF_4 ratios of the taggant gases as placed in the structure and in the cloud (the ratio for the cloud was obtained using the Tonka uplooking spectrometer) and determined that, within the measurement uncertainties, no thermal decomposition of the taggant gases occurred for this event (Herr *et al.* 1997a).

4.2.3 Ground Sampling.

Aerosol samplers were placed on the ground in a nearly circular array surrounding the DIPOLE ORBIT 5 structure at a distance of approximately 1 km and in a second irregular array at distances of 2-12 km (Larsen 1996b). For the 1-km sampler array, the maximum CFU count was obtained at an azimuth of 226 deg (400/sample). For the second array, the maximum CFU count occurred at 263 deg (160/sample). Samplers with CFU counts greater than 100/sample are shown in Figure 4-8 by the solid square symbols. With the one exception in the second array at 263 deg, all of these samplers were in the 1-km arc from 156 to 232 deg. Additional positive CFU counts in the range from 11 to 100 per sample occurred throughout the azimuth range of the 1-km array and from northwest to east of the structure for the second array (half-solid square symbols). Sampler locations with zero CFU counts are shown in Figure 4-8 by the open square symbols (many samplers with zero CFU counts are beyond the borders of the figure). The CFU counts for the samplers in the second array at 263 deg (the one with the high count) and 328 deg (17 counts/sample) appear to be inconsistent with the bulk of the results.

4.2.4 Discussion.

The DIPOLE ORBIT 5 cloud dissipated rapidly and moved slowly in a generally eastward direction, causing some difficulty in tracking. The manual real-time cloud tracking operations produced triangulated cloud positions for 30 min after the detonation. The cloud range from the structure was approximately 2 km at 30 min after the detonation (Figure 4-8). The Ram Van spectrometer continued to provide cloud azimuth data to a total time of 28.5 min after the detonation; however, additional sensors were not available to triangulate on cloud position. The Tonka vehicle was successfully directed to positions where it intercepted the cloud at times from 7 to 63 min after the detonation at ranges from 0.8 to 8 km.

The IR sensors, tracking the SF_6 cloud, provided triangulated results for cloud position and dimensions for about 5 times as long as the visible sensors (video and film cameras), which tracked the visible (dust) cloud. The visible cloud top was much higher than the IR (SF_6) cloud top. This result suggests that the SF_6 was released from the structure later than the dust cloud as a result of the below ground position of the weapon.

From the ground sampler results Larsen (1996b) determined that the cloud travel was primarily toward the southwest at a heading of 225 deg. This was nearly opposite to the ultimate direction determined from the real-time cloud track, which was in good agreement with the wind vector from the radiosonde (Figure 4-8), for the first 30 min after the detonation. The cloud track determined by Logicon RDA from the video records indicated an initial motion toward the south, followed by a spiral track with a final direction approximately along the wind vector. The latest cloud intercept by The Aerospace Corporation's Tonka vehicle occurred at 63 min after the detonation near Oscura Gap, almost directly east of the structure (Herr *et al.* 1997a). Several samplers with CFU counts in the 11-100 per sample range were northeast to east of the structure, in the cloud path as indicated by the wind vector and the cloud intercepts by the Tonka vehicle. It is possible that the large number of samples in the 1-km arc with positive CFU counts intercepted the edge of the cloud as it expanded and turned toward its final heading.

4.3 DIPOLE EAST 159.

4.3.1 Real-Time Cloud Tracking.

The DIPOLE EAST 159 cloud was tracked manually in real time from 5 to 105 min after the detonation. These positions are shown by the solid circle symbols in Figure 4-11. There appeared to be two separate clouds, one moving north-northwest (which could not be detected beyond 10 min after the detonation) and the other moving north-northeast along WSMR Route 13. As discussed in Section 4.3.2, none of the fixed Aerospace sensors recorded the cloud after 14 min. The azimuths reported during cloud tracking operations were real-time observations made by the instrument operators.

The Tonka vehicle detected the cloud on WSMR Route 13 approximately 0.7 km northwest of the structure at 7 to 10 min after the detonation. The Tonka positions at 9 min after the detonation and at later cloud intercepts at 41, 158, 161, 237, and 299 min after the detonation are shown by the open circle symbols in Figure 4-11. The intercept at 9 min appeared to be with the cloud segment that moved to the northwest.

4.3.2 Post-Event Analyses.

4.3.2.1 Cloud Track. The Aerospace Corporation was unable to conduct their usual post-event triangulation analysis of the cloud track because only one of their sensors (the Snoopy sensor) successfully tracked the cloud (Herr *et al.* 1997b). Aerospace believed that the combustion of the biological simulant in the structure raised the temperature to levels sufficient to dissociate some of the SF_6 and CF_4 taggant gases, removing a substantial fraction of the IR emission from the cloud. Also, the atmospheric conditions, high absolute humidity with significant clouds, were poor for IR viewing. As a result, the only cloud position information was that given in Section 4.3.1 for the Tonka vehicle.

Logicon RDA (Allen 1996b) analyzed the visible video records for 3 min after the detonation. The results shown were triangulated from the camera locations the WB-1 and TRS Park sites. These results are given by the + symbols in the larger display in Figure 4-12.

ISI (Dudziak 1996b) obtained a cloud track from the analysis of the large format film records for 1.3 min after the detonation. These results were obtained from cameras located at the EZ-8 and Gus sites (triangle symbols in Figure 4-12).

Both Logicon RDA and ISI tracked the cloud segment that moved north-northeast. The cloud positions determined by Logicon RDA were in good agreement with the 5 min position from the real-time cloud track (Figure 4-12). The ISI cloud positions were well ahead of those determined by Logicon RDA.

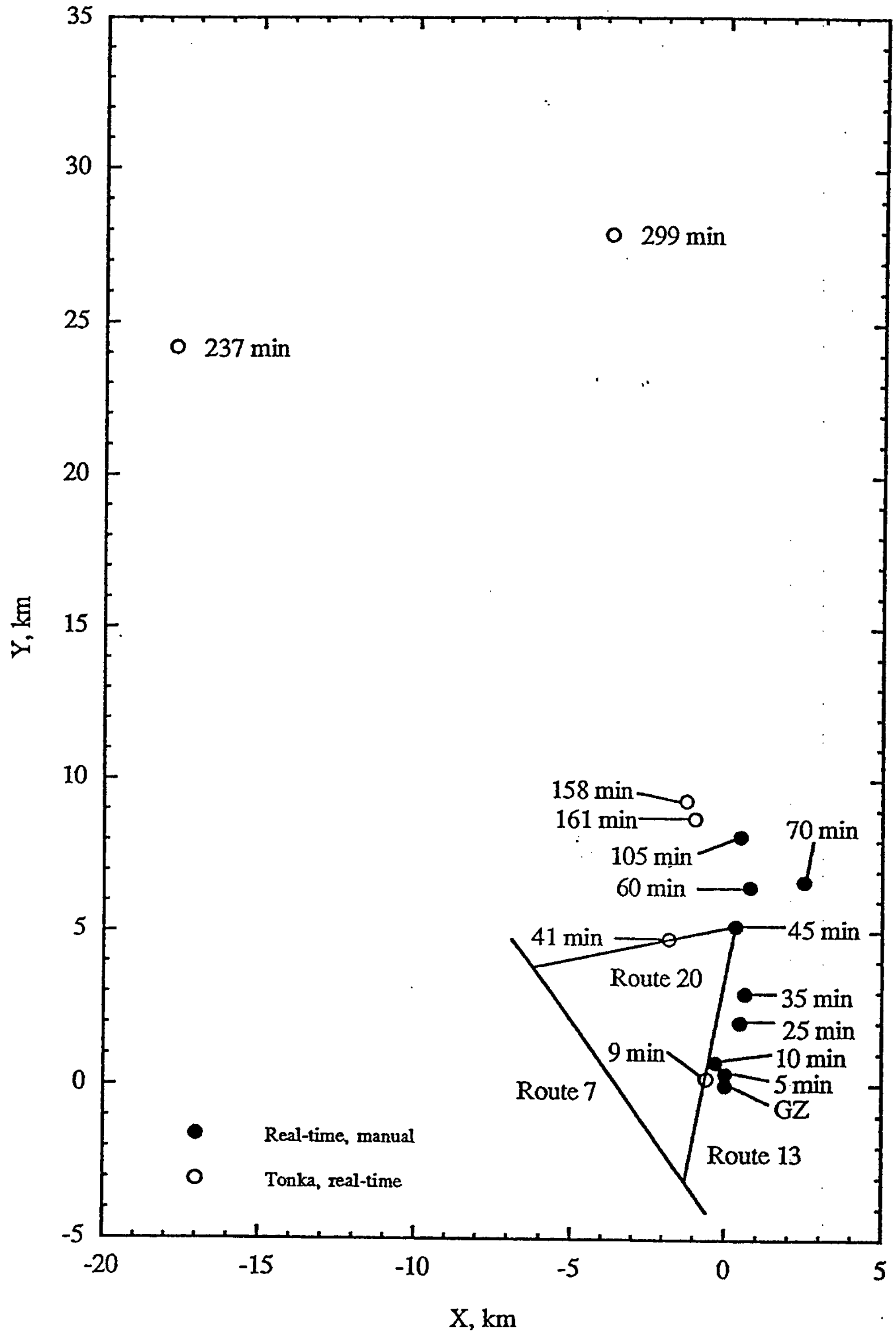

Figure 4-11. DIPOLE EAST 159 cloud track results.

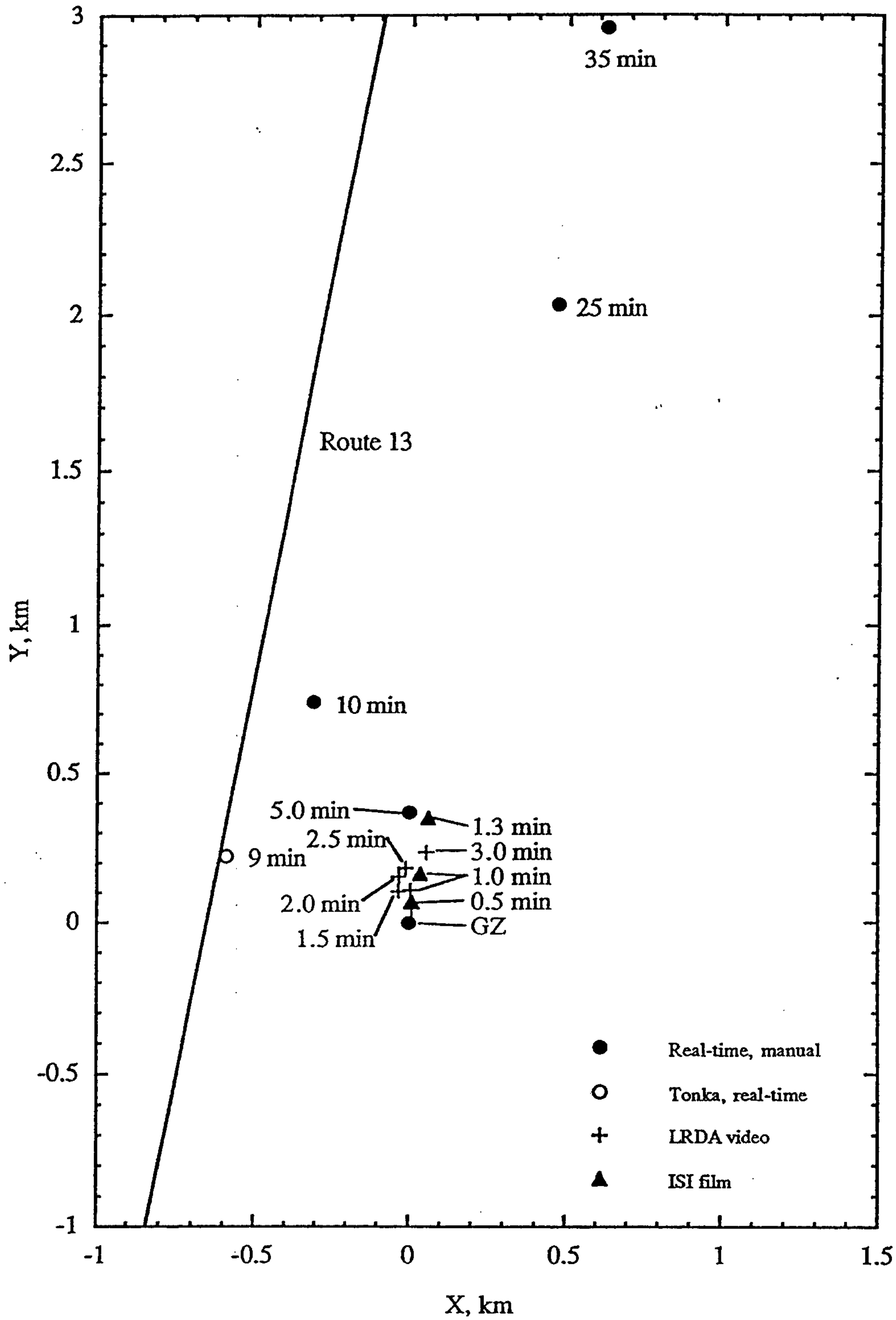

Figure 4-12. DIPOLE EAST 159 cloud track results (enlarged view).

4.3.2.2 Cloud Dimensions. The Aerospace Corporation determined the cloud top height as a function of time from data acquired by the Snoopy sensor (Herr *et al.* 1997b). Figure 4-13 gives the Aerospace results for 0.17 to 2 min after the detonation (x symbols).

Logicon RDA (Allen 1996b) determined the cloud top height from the visible video records for 3 min after the detonation using the cameras located at the TRS Park and WB-1 sites and for 2.5 min using the cameras located at Camera Bunker A and the WB-1 site. These results are shown in Figure 4-13 (+ symbols).

ISI (Dudziak 1996b) reported cloud top heights from the large format film records at the EZ-8 site for 1.3 min and the Gus site for 2 min after the detonation. These results are given by the triangle symbols in Figure 4-13.

The cloud heights determined by Aerospace and Logicon RDA are in good agreement, indicating that the dust and SF_6 were well mixed. The ISI results are inconsistent.

Cloud widths were determined by Aerospace, Logicon RDA, and ISI. The Aerospace results were obtained using images from a visible video camera (Herr *et al.* 1997b). Figure 4-14 presents these results using the same symbols as Figure 4-13.

The cloud widths are in reasonable agreement except for the Logicon RDA results determined from the TRS site. It is possible that the two clouds appeared as a single larger cloud from this site.

4.3.2.3 Meteorological Observations. The weather on shot day for event DIPOLE EAST 159 was humid for WSMR and hot, and the sky was cloudy. The "slow rise" radiosonde was launched from West Park at shot time. This sensor provided meteorological conditions from the surface to an altitude of approximately 4600 m MSL. Figure 4-4 gives the wind direction versus altitude. There was a large directional wind shear between the near ground layer (from about 150 deg) and the higher altitudes (wind from approximately 290 deg). Apparently the low cloud height kept the cloud within or near the top of the ground layer. At the tower located at the

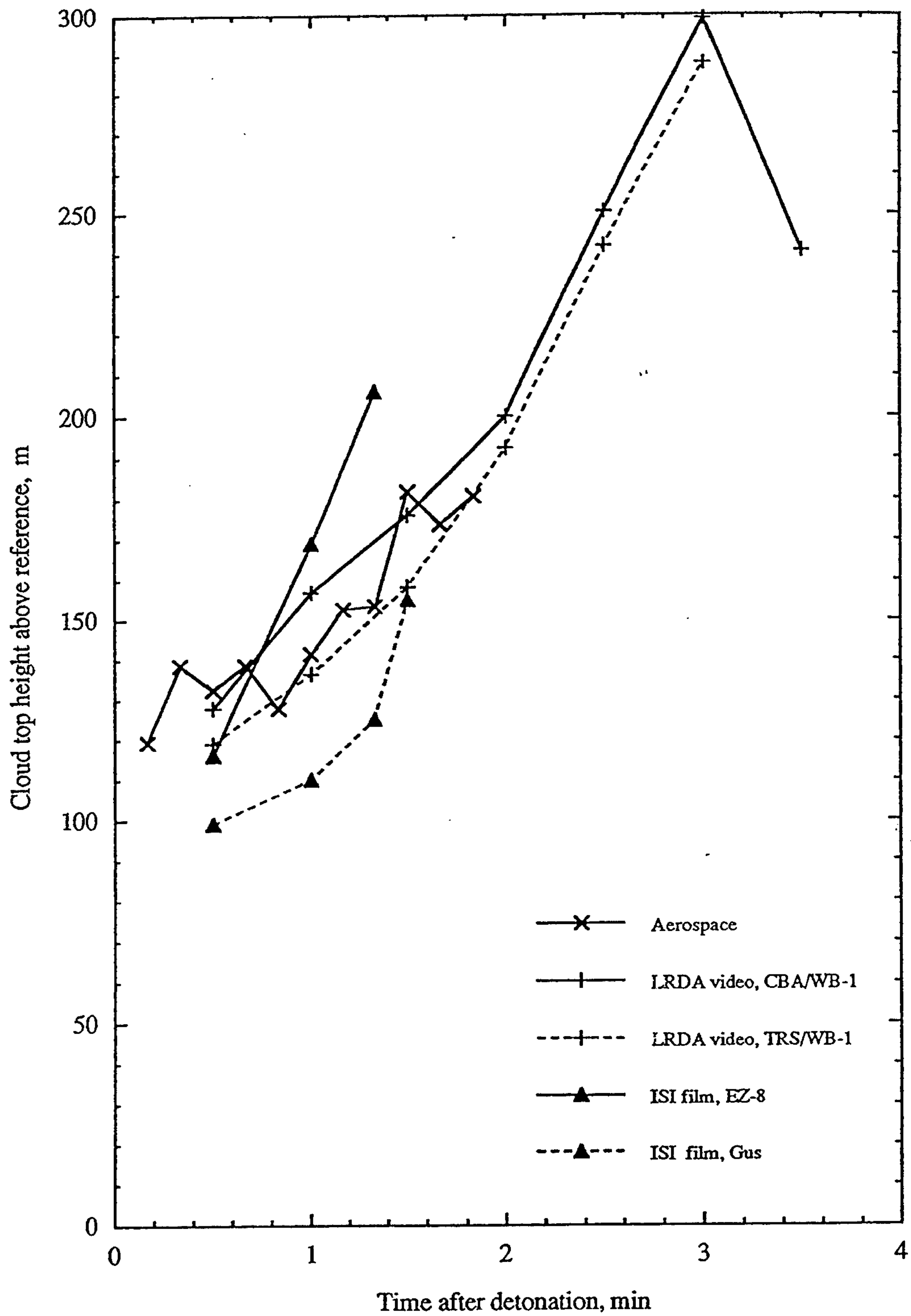

Figure 4-13. DIPOLE EAST 159 cloud heights.

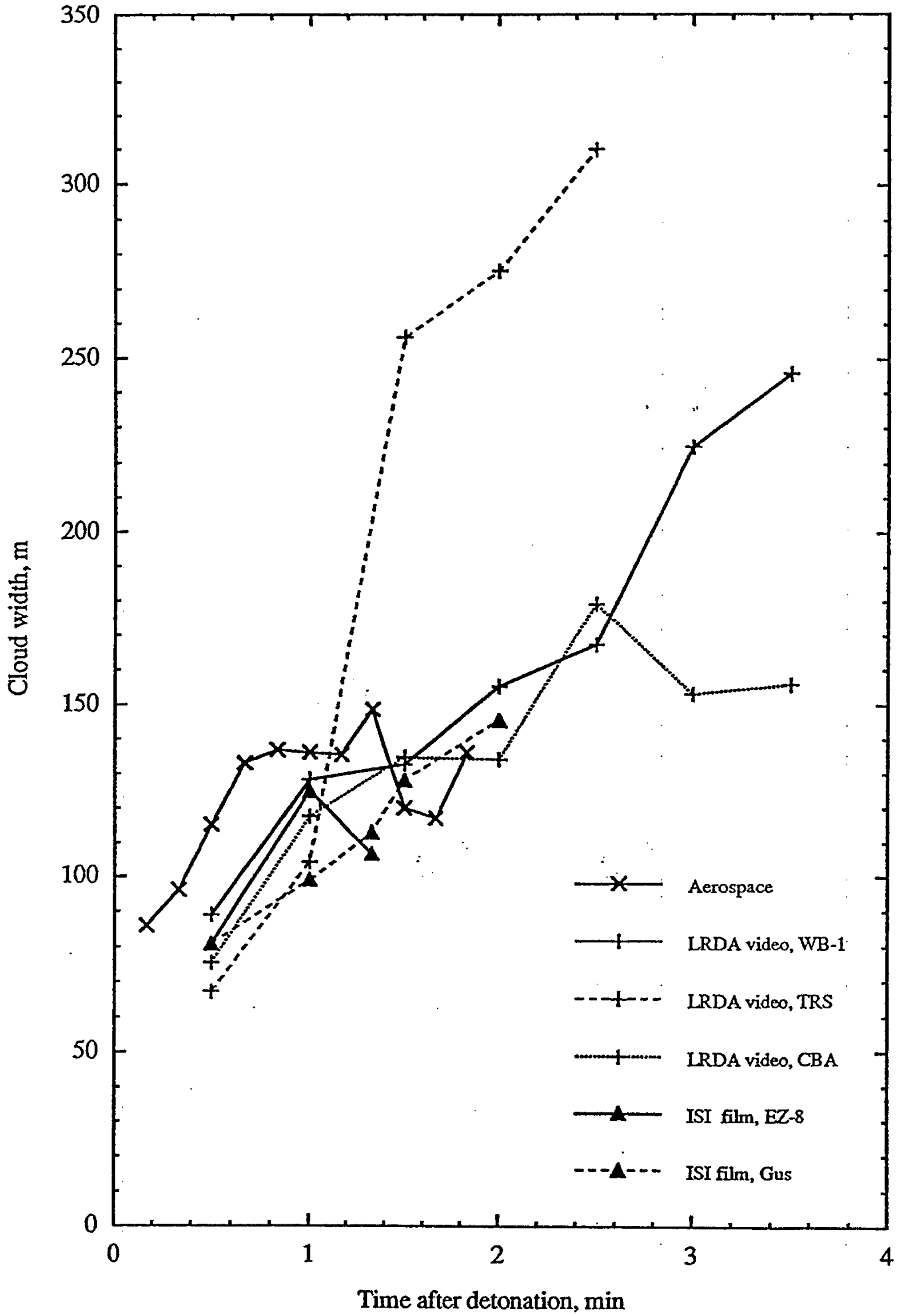

Figure 4-14. DIPOLE EAST 159 cloud widths.

structure, the wind direction at the detonation time was from 230 deg (Jameson 1996b). By 10 min after the detonation, the wind direction at the tower had changed to 160 deg. The variable nature of the wind probably contributed to the uncertainty in the cloud track and the rapid dispersion of the cloud.

Figure 4-5 gives the wind speed versus altitude. The wind speeds were low (1-3 m/s) below 3000 m MSL.

Figure 4-6 gives the air temperature versus altitude. No inversions were present.

4.3.2.4 Taggant Gas Results. The Aerospace Corporation sidelooking spectrometer at the Snoopy site measured a peak SF_6 column density of about 5 ppm-m at 4 min after the detonation (Herr *et al.* 1997b). The peak column density measured by this sensor decreased to about 1.2 ppm-m at 13 min after the detonation.

The uplooking spectrometer in the Tonka vehicle measured a maximum vertical SF_6 column density of 2.5 ppm-m at 8 min after the detonation. The peak SF_6 concentration at ground level measured by the gas chromatograph at the same time was nearly 14 ppb. During the intercept along WSMR Route 20 at 28-44 min after the detonation the peak SF_6 concentration at ground level measured by the gas chromatograph (no further readings were obtained using the spectrometer) was about 70 ppt. Levels decreased to 10 ppt at the later intercepts north of Trinity site (158-161 min after the detonation). Trace amounts of SF_6 were detected near Stallion Gate (237 min on Figure 4-11) and along US Highway 380 (299 min on Figure 4-11). These concentrations were near the detection threshold of the instrument (Herr *et al.* 1997b).

Aerospace measured the SF_6/CF_4 ratios of the taggant gases as placed in the structure, in the detonation cloud, and remaining in the structure 3 hrs after the detonation. The ratio for the detonation cloud (determined using the results of the Tonka uplooking spectrometer at 6-9 min after the detonation) was 0.44 compared to the pre-event ratio of 1.55 (Herr *et al.* 1997b). The SF_6/CF_4 ratio for the gases remaining in the structure post-event was 0.22. The Aerospace Corporation asserted that the low ratios in the detonation cloud and in the structure, the low column densities of SF_6 (relative to other events), and observed spectra of silicon tetrafluoride in the detonation cloud resulted from temperatures above the decomposition temperature of SF_6 and CF_4 in the structure immediately following the detonation. The low SF_6 concentrations in the detonation cloud and the cloudy background reduced the ability of The Aerospace Corporation to perform their post-event analysis of the cloud for event DIPOLE EAST 159.

4.3.3 Ground Sampling.

Aerosol samplers were placed on the ground in two arrays for event DIPOLE EAST 159 (Larsen 1996c). The samplers in the near array were north to northeast of the structure at ranges from about 12 to 18 km (Figure 4-15). The maximum Bg CFU count for this array was 373 counts/ sample at an azimuth of 32.3 deg. CFU counts of 20/sample and greater were obtained throughout the array (all samplers represented by solid symbols on Figure 4-15 had positive CFU counts and all samplers represented by open symbols had zero CFU counts). The samplers in the far array were northwest to northeast of the structure at ranges from about 29 to 42 km. The

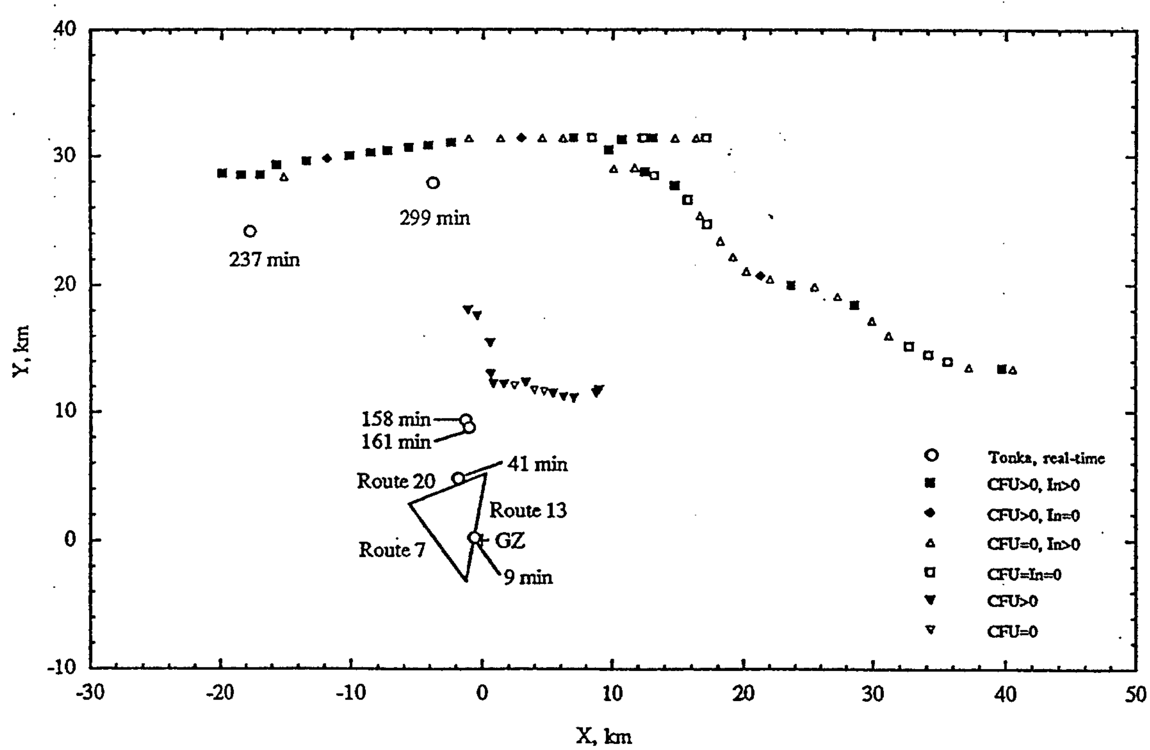

Figure 4-15. DIPOLE EAST 159 ground sampling results.

higher CFU counts were obtained toward the western end of this array. The maximum CFU count for this array occurred at an azimuth of 349.5 deg (247 counts/sample). Results were not available for 38 samplers in the far array; we believe that most of these samplers were located in the eastern half of this array and registered zero CFU counts.

The material recovered from 52 samplers in the far array was analyzed for the rare earth tracer incorporated into the Bg mix (Mason and Finnegan 1996). The solid square symbols in Figure 4-15 represent samplers with positive CFU counts and detectable indium (20 of 52 samplers). The solid diamond symbols represent samplers with positive CFU counts and zero indium (3 samplers). The open upright triangle symbols represent samplers with zero CFU counts and positive indium (20 samplers). The open square symbols represent samplers with zero CFU counts and zero indium (9 samplers). Overall, slightly more than half of the samples showed agreement between positive Bg CFU counts and the indium tracer (either both positive or both zero).

4.3.4. Discussion.

The DIPOLE EAST 159 detonation cloud was tracked in real time for 105 min after the detonation in light winds. The last cloud position was approximately 8 km from the structure. The Tonka vehicle intercepted the cloud at ranges from 0.7 to about 10 km from the structure and detected SF_6 at ranges as great as 30 km from the structure 5 hr after the detonation.

The Aerospace Corporation was unable to obtain useful data from their recorded IR sensor data beyond 14 min after the detonation. This was attributed to dissociation of the taggant gases inside the structure and poor IR viewing conditions resulting from the high atmospheric humidity and cloudy sky. This did not adversely affect the ability to track the cloud in real time (the Agema 1, Agema 3, and WES IR cameras maintained contact with the cloud for most of the tracking period).

Cloud tracking operations personnel were able to extrapolate the direction and speed of cloud travel sufficiently accurately to permit the capture of ground samples at ranges of 30 km and greater, well beyond the range of the real-time cloud track. Figure 4-15 compares the sampler results to the Tonka cloud intercept locations at 6 times after the detonation for event DIPOLE EAST 159 (the points for the Tonka intercepts at 161, 237, and 299 min each represent several intercepts over periods of several min, see Herr *et al.* 1997b). The Tonka intercepts all occurred within the azimuth range of about 320 to 360 deg. The highest CFU counts for the far ground sampler array were also within this azimuth range (the near ground sampler array did not cover this azimuth range). Significant CFU counts were also obtained within the azimuth range of about 0 to 40 deg, especially for the near sampler array. The Tonka vehicle did not traverse the area of the near sampler array. The SF_6 concentration (if actually nonzero) was below the lower detection limit of Tonka's gas chromatograph as it passed the far array east of 0 deg. Overall, the results for the long-range sensors (the Tonka vehicle and the ground samplers) were in good agreement for this event.

The ground sampling results indicated positive CFU counts and positive indium at both ends of the far array and positive CFU counts at both ends of the near array (no neutron activation results were available for the near array). The edges of the cloud could not be determined from these results. The cloud was obviously very large as it passed over the far sampling array. This was probably a result of the light and variable nature of the winds.

4.4 DIPOLE ORBIT 3.

4.4.1 Real-Time Cloud Tracking.

The manually generated locations of the cloud centroid for the DIPOLE ORBIT 3 event are shown by the solid circle symbols in Figure 4-16 for times from 5 to 25 min after the detonation. The cloud moved toward the northeast over the Oscura Mountains.

The Tonka vehicle first intercepted the cloud at a distance of about 7 km from the structure, where it obtained both spectroscopic and gas chromatography measurements, at 15-20 min after the detonation. This location is shown by the open circle symbol in Figure 4-16 (at 17.25 min). Additional intercepts occurred at 33 km from the structure at 80 min after the detonation, and 80

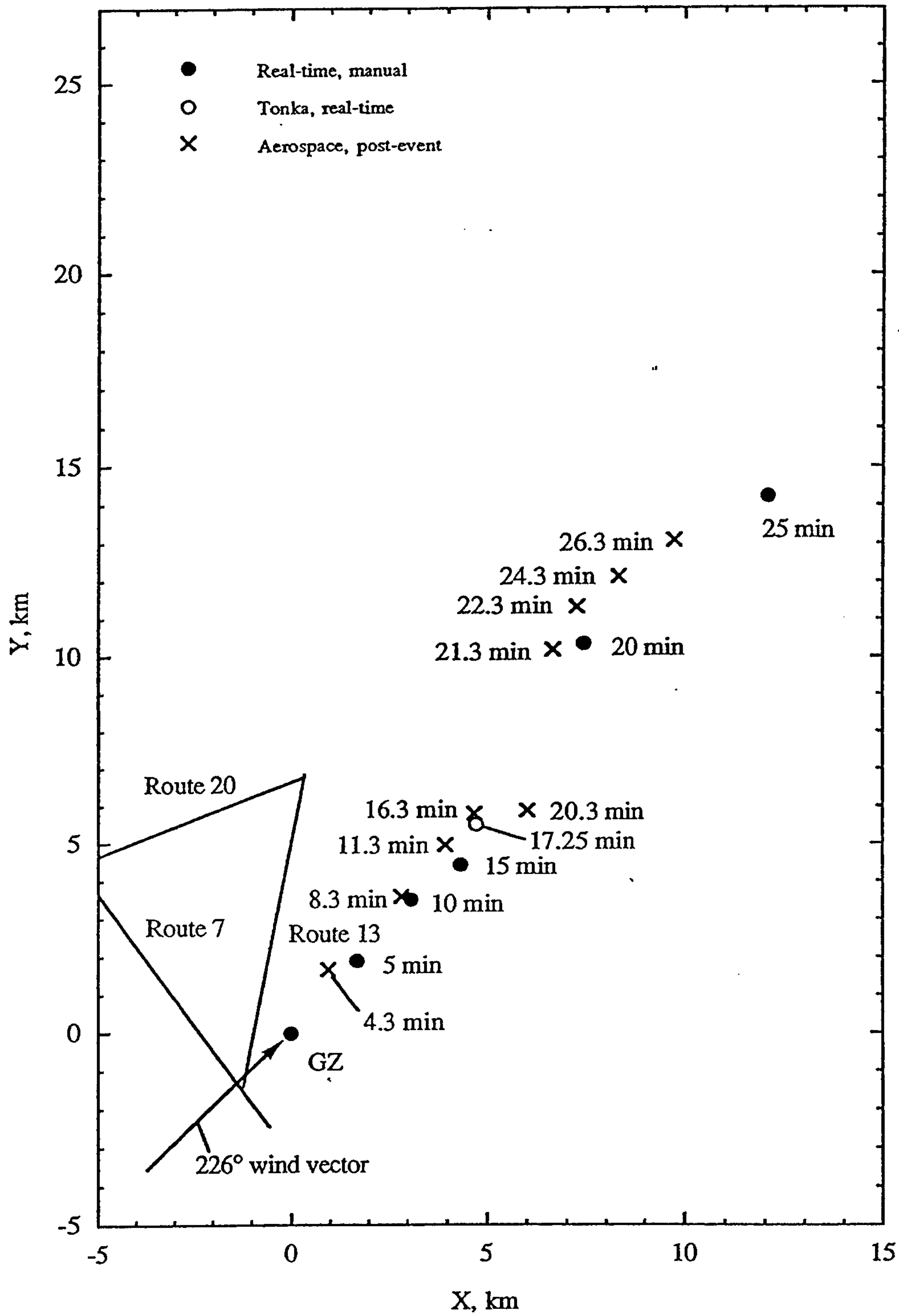

Figure 4-16. DIPOLE ORBIT 3 cloud track results.

km from the structure at 190 min after the detonation. Only gas chromatography measurements were obtained at the latter two locations.

4.4.2 Post-Event Analyses.

4.4.2.1 Cloud Track. The Aerospace Corporation conducted a post-event analysis of the cloud tracking results for their sensors for times from 4.3 to 26.3 min after detonation (Herr *et al.* 1997c). Aerospace noted that the cloudy sky and the need to view the cloud against the terrestrial background caused less than ideal IR viewing conditions resulting in possible errors in the cloud location. The post-event Aerospace track is shown by the x symbols in Figure 4-16. At 20.3 min after the detonation two sensors observed different portions of the cloud, resulting in difficulty in triangulation.

4.4.2.2 Cloud Dimensions. The Aerospace Corporation determined the cloud top height as a function of time from data acquired by the three Agema IR cameras. Figure 4-17 gives the Aerospace results for 11 min after the detonation (x symbols). The bottom of the cloud appeared to remain close to the ground (Herr *et al.* 1997c).

ISI (Dudziak 1997b) reported cloud top heights from the large format film records for 2 min after the detonation. These results are given by the triangle symbols in Figure 4-17.

The cloud heights from all sensors are in reasonable agreement for the initial 5 min after detonation (Figure 4-17). The decreases in height after the maxima for the Aerospace sensors appeared to be caused by loss of sensitivity and should be disregarded.

Cloud widths were determined by Aerospace and ISI. Figure 4-18 presents these results using the same symbols as Figure 4-17.

The cloud widths for the DIPOLE ORBIT 3 cloud depended strongly on the alignment of the viewing instrument relative to the direction of cloud movement (Herr *et al.* 1997b). The

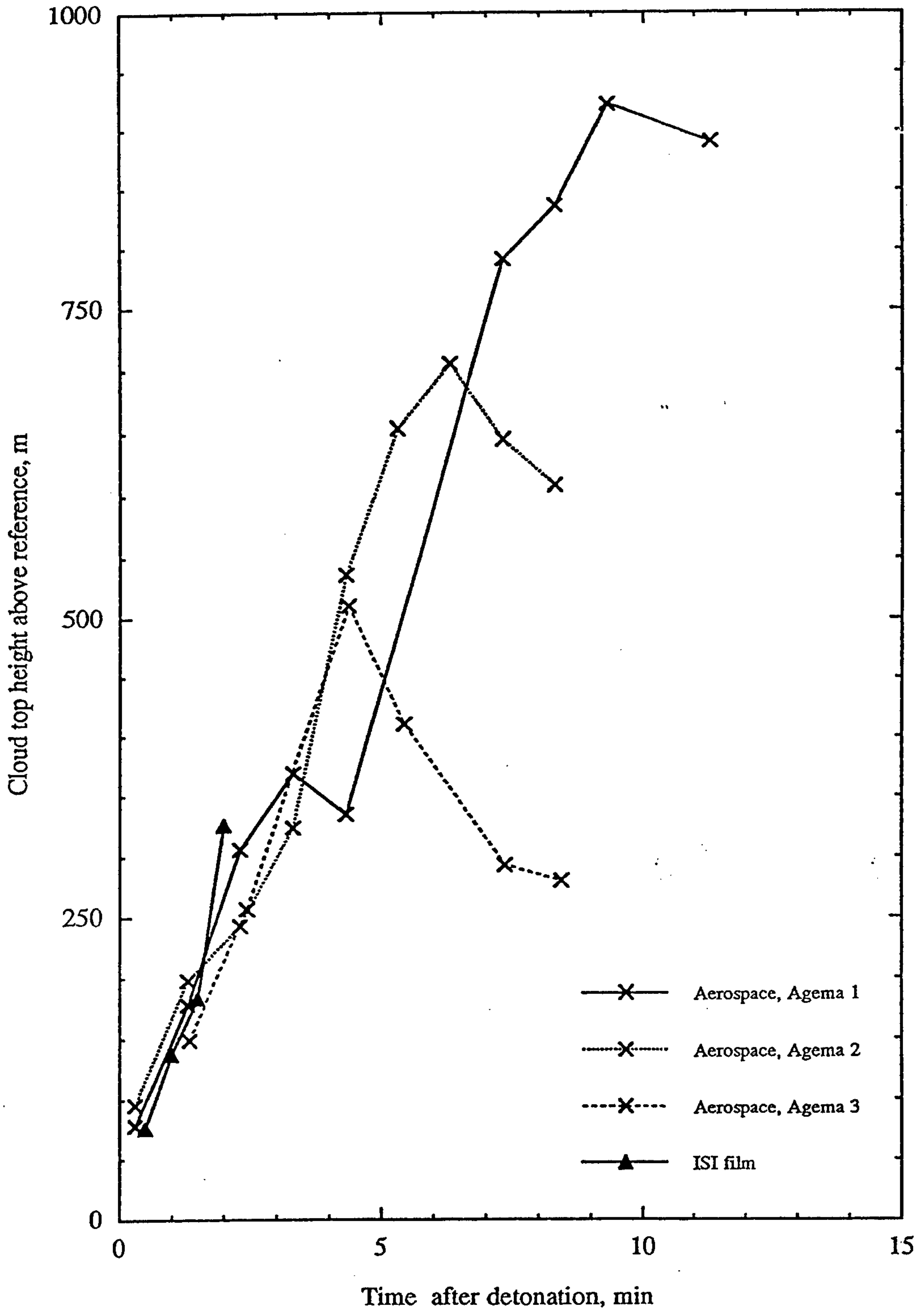

Figure 4-17. DIPOLE ORBIT 3 cloud heights.

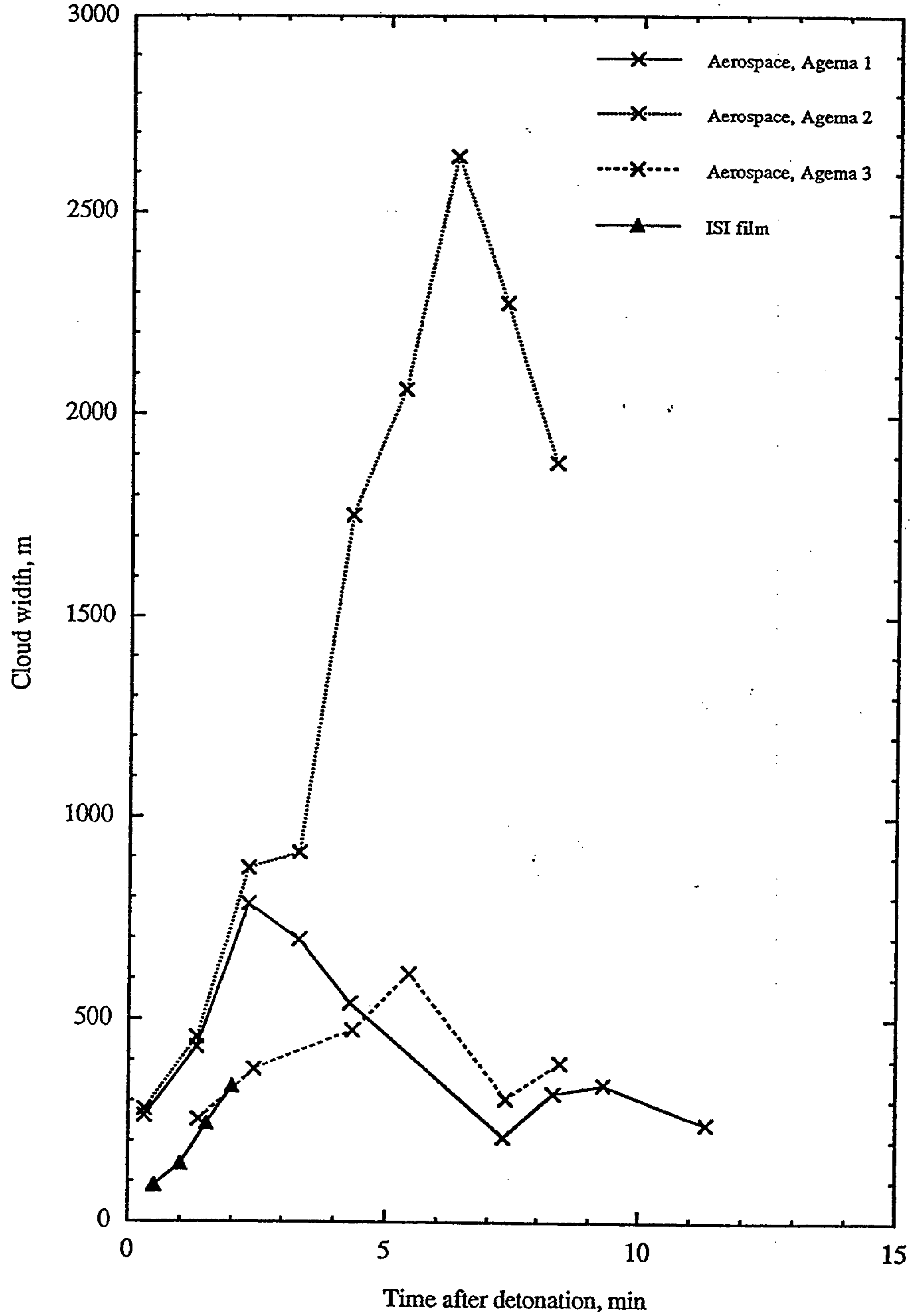

Figure 4-18. DIPOLE ORBIT 3 cloud widths.

Agema 2 IR camera viewed the cloud from the side and therefore observed the largest cloud width. The Agema 3 IR camera viewed the cloud from upwind and observed the smallest cloud width. The view of the Agema 1 IR camera changed with time. The ISI film camera had a view similar to that of the Agema 3 camera and obtained similar results.

4.4.2.3 Meteorological Observations. The weather on shot day for event DIPOLE ORBIT 3 was mild and the sky was partly cloudy. The "slow rise" radiosonde was launched from West Park Bunker 22 min after the detonation. This sensor provided meteorological conditions from the surface to an altitude of approximately 3600 m MSL. Figure 4-4 gives the wind direction versus altitude. The wind was from 226+3 deg to 2750 m MSL, rotating slightly toward the west at higher altitudes. The mobile profiler gave wind directions of 157 deg at 460 m AGL and 254 deg at 1040 m AGL at 10 min after the detonation (DeRego 1997a).

Figure 4-5 gives the wind speed versus altitude. The wind speeds were high (12-13 m/s) at all altitudes of interest. The cloud speeds determined by The Aerospace Corporation during the post-event analysis were from 7 to 11 m/s.

Figure 4-6 gives the air temperature versus altitude. A weak inversion was present at 3300 m MSL. This was too high to affect the detonation cloud.

4.4.2.4 Taggant Gas Results. The Aerospace Corporation sidelooking spectrometer in the Ram Van measured peak SF_6 column densities from about 2.5 to 5 ppm-m (Herr *et al.* 1997c). The uplooking spectrometer in the Tonka vehicle measured a maximum vertical SF_6 column density of 6.5 ppm-m during the intercept beginning 12.5 min after the detonation. The peak SF_6 concentration at ground level measured by the gas chromatograph during the same intercept was 17 ppb. At 80 min after the detonation the peak concentration was 15 ppt, which Aerospace concluded corresponded to the edge of the cloud (Herr *et al.* 1997b). A higher concentration, 25 ppt, was measured at 190 min after the detonation.

4.4.3 Ground Sampling.

Aerosol samplers were placed on the ground in two arrays for event DIPOLE ORBIT 3 (Larsen 1997). The samplers in the near array were northeast to southeast of the structure at ranges near 1 km (Figure 4-19). The maximum Bg CFU count for this array was 1.6×10^6 counts/sample at an azimuth of 45.5 deg. CFU counts greater than 1.5×10^5/sample were obtained for azimuths from 34.4 to 45.5 deg (larger solid square symbols). Lower CFU counts were obtained in both directions from the high values (smaller solid square symbols). The samplers in the far array were also northeast to southeast of the structure and were at ranges from about 6 to 12 km. The only CFU counts were obtained at the western end of this array (smaller solid square symbols). The maximum CFU count for this array occurred at an azimuth of 39.4 deg (5760 counts/ sample), which was the most westerly sampler in the array. Zero CFU counts were obtained at both ends of the near array (where some points were left out for clarity) and for most of the far array (open symbols).

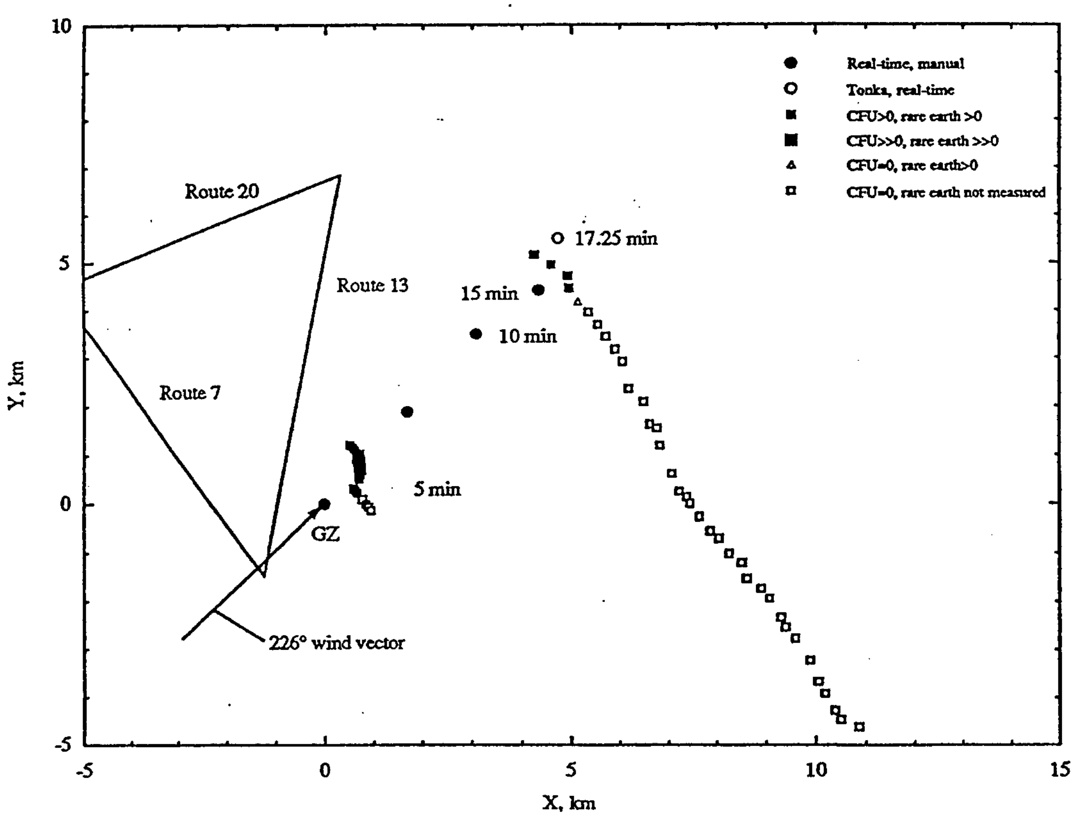

Figure 4-19. DIPOLE ORBIT 3 ground sampling results.

Mason and Finnegan (1997b) performed neutron activation analysis for a selected set of ground samples (azimuths from 22.8 to 71.6 deg for the near array and from 39.4 to 50.8 deg for the far array). This set included all of the samples with positive CFU counts plus one adjacent sample with zero CFU count for each array. Significant levels of indium or dysprosium were found in all of the analyzed samples. The correlation between these tracers and the Bg and Bt counts was good for both arrays (see Mason and Finnegan 1997b for further discussion).

4.4.4 Discussion.

The cloud tracking operations for event DIPOLE ORBIT 3 were the first conducted during high wind speed conditions. The real-time cloud tracking operations produced triangulated cloud positions for 25 min after the detonation. The cloud range from the structure was approximately 18 km at 25 min after the detonation (Figure 4-16). The Tonka vehicle was successfully directed to positions where it intercepted the cloud at times from 12 to 190 min after the detonation at ranges from 7 to 80 km.

Cloud intercepts using the Tonka vehicle were made after the cloud passed over the Oscura Mountains and the initial continuous track had been interrupted. This accomplishment conclusively demonstrated that the cloud could be reacquired by positioning the sensors using the predictive tools, wind measurements, and the initial real-time cloud track.

Figure 4-19 compares the sampler results to the real-time cloud track and the Tonka cloud intercept location nearest the structure for event DIPOLE ORBIT 3. The results for all sensors were in excellent agreement for this event.

The ground sampling results indicated zero CFU counts at both ends of the 1-km sampling array, suggesting a cloud width of approximately 0.8 km (perpendicular to the direction of cloud motion) at a time of 1-2 min after the detonation. This is substantially larger than the cloud width determined using the IR and optical sensors with the same view of the cloud. At ranges near 6-7 km only the easterly edge of the cloud could be determined from the CFU counts and a total cloud width could not be estimated. The rare earth results were inconclusive with respect to cloud edges.

4.5 DIPOLE ORBIT 6.

4.5.1 Real-Time Cloud Tracking.

The manually generated locations of the cloud centroid for the DIPOLE ORBIT 6 event are given by the solid circle symbols in Figure 4-20 for times from 5 to 50 min after the detonation. The cloud moved toward the northeast and over the Oscura Mountains and the track was maintained well beyond the mountains. The Tonka vehicle intercepted the cloud at distances of about 30-32 km from the structure at 46-71 min after the detonation and 62-65 km at 106-110 min after the detonation (all gas chromatography measurements).

4.5.2 Post-Event Analyses.

4.5.2.1 <u>Cloud Track</u>. The Aerospace Corporation conducted a post-event analysis of the cloud tracking results for their sensors for times from 6 to 41 min after detonation (Herr *et al.* 1997d). The post-event Aerospace track is shown by the x symbols in Figure 4-20.

4.5.2.2 <u>Cloud Dimensions</u>. The Aerospace Corporation determined the cloud top height as a function of time from data acquired by the TopKick spectrometer and two Agema IR cameras. Figure 4-21 gives the Aerospace results for 34 min after detonation. The bottom of the cloud appeared to remain close to the ground (Herr *et al.* 1997d).

Cloud widths along and across the cloud path were determined by Aerospace. Figure 4-22 presents these results.

4.5.2.3 <u>Meteorological Observations</u>. The weather on shot day for event DIPOLE ORBIT 6 was cool and the sky was partly cloudy. The "slow rise" radiosonde was launched from West Park Bunker 30 min after the detonation. This sensor provided meteorological conditions from the

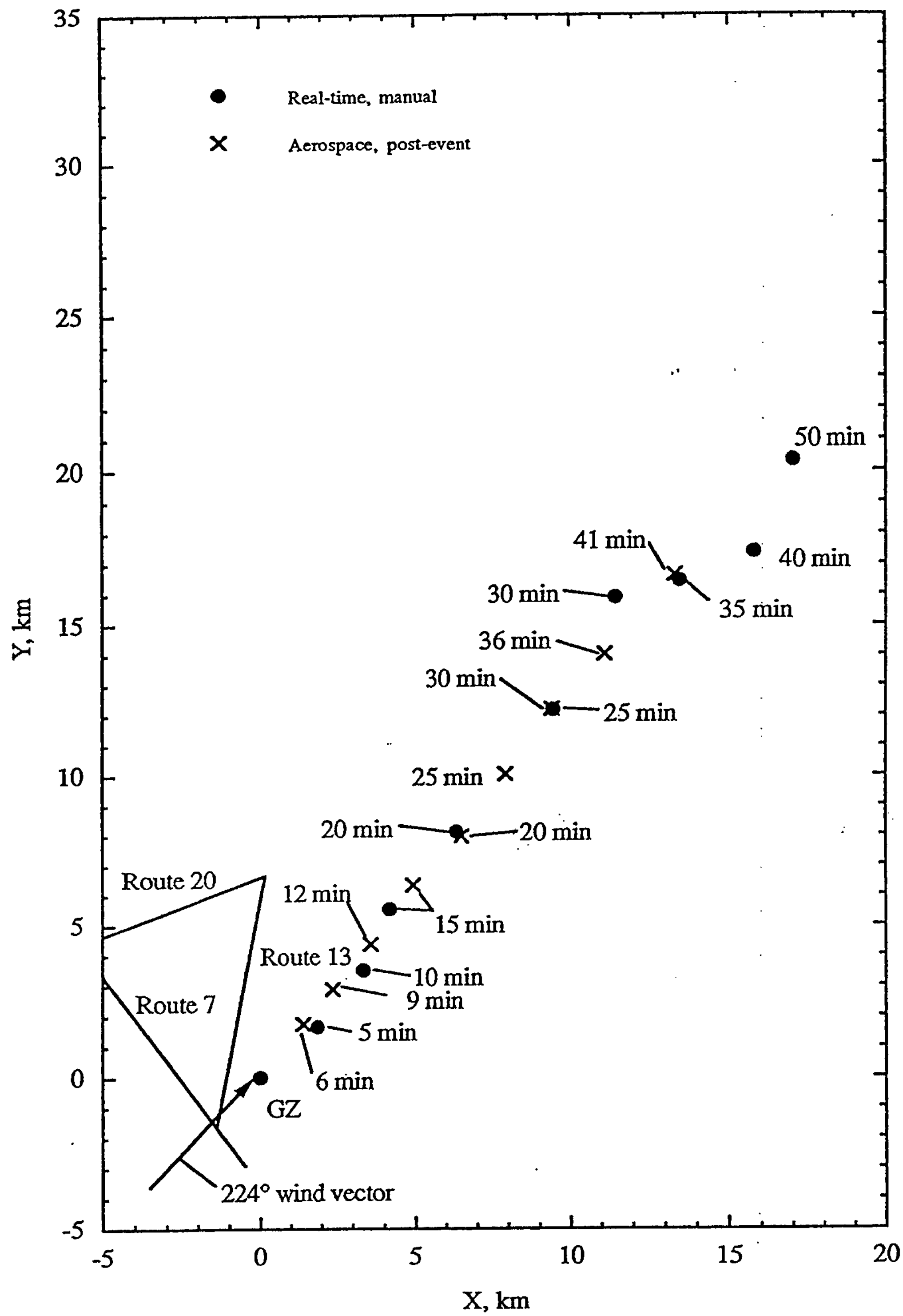

Figure 4-20. DIPOLE ORBIT 6 cloud track results.

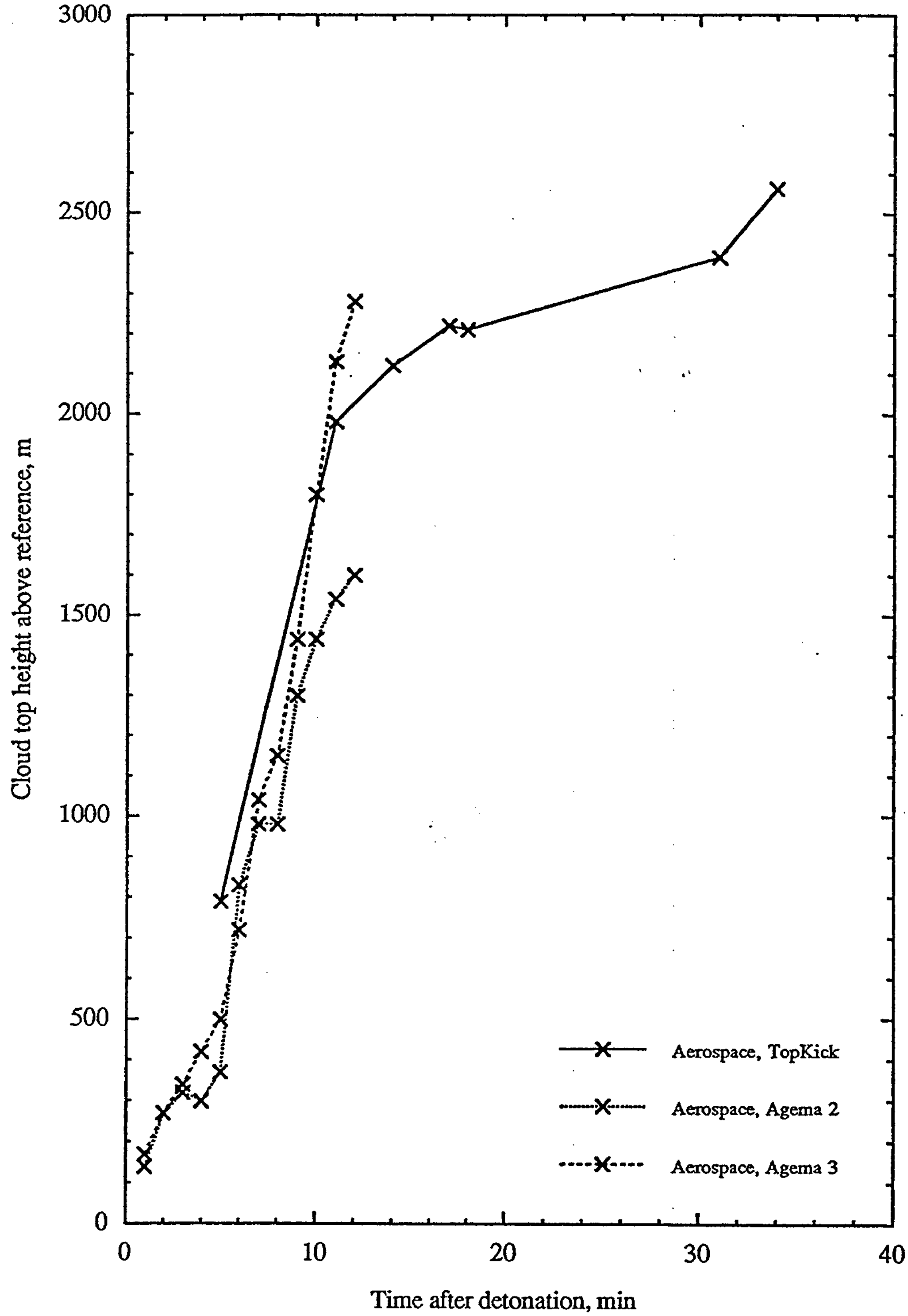

Figure 4-21. DIPOLE ORBIT 6 cloud heights.

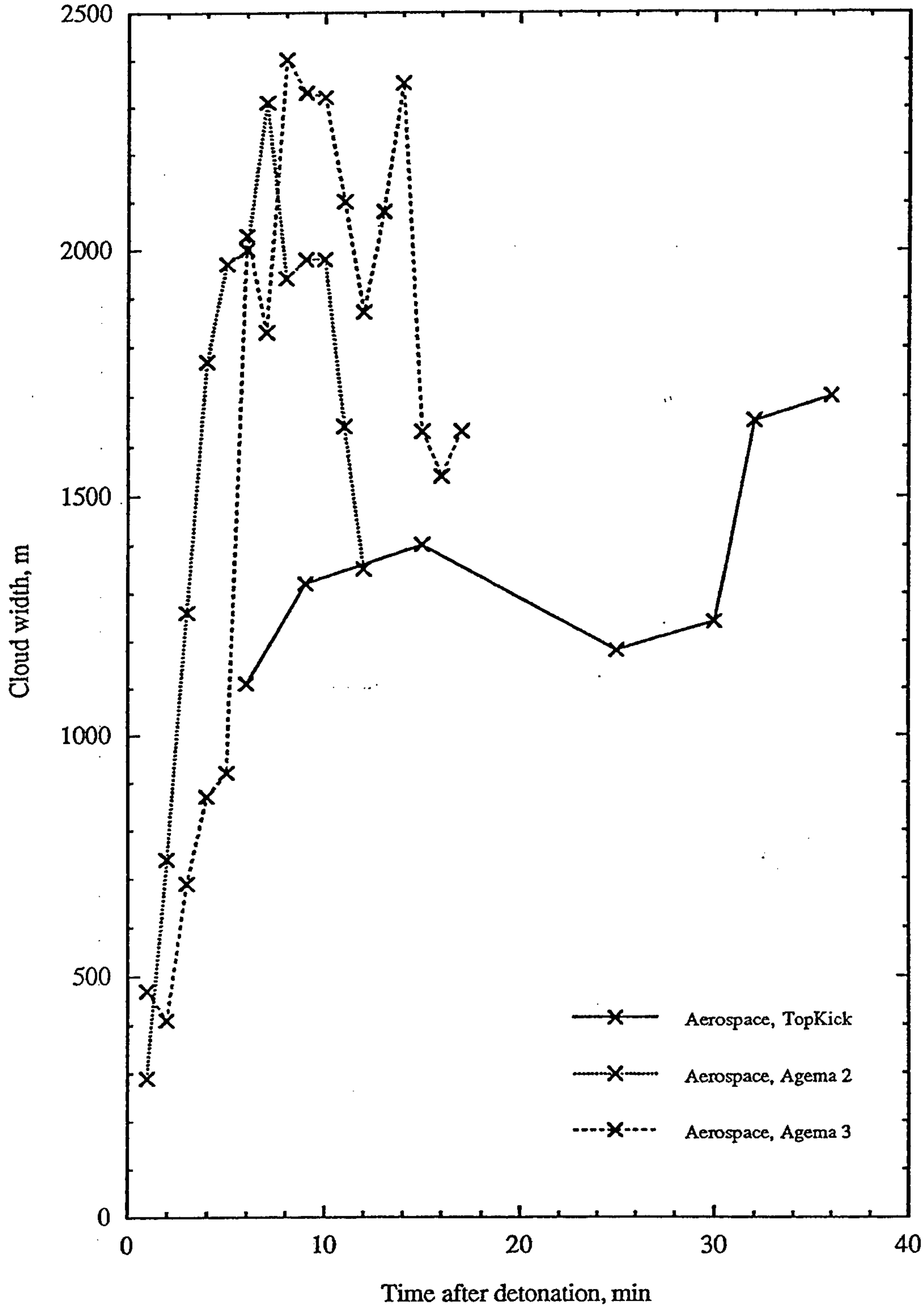

Figure 4-22. DIPOLE ORBIT 6 cloud widths.

surface to an altitude of approximately 3000 m MSL. Figure 4-4 gives the wind direction versus altitude. The wind was from 240 deg at the surface and from 224+8 deg above 40 m AGL. At the tower located near the Air Force 1 structure, the wind direction at the detonation time was from 217 deg (DeRego 1997b).

Figure 4-5 gives the wind speed versus altitude. The wind speeds were high (11-13 m/s) above about 1800 m MSL. The cloud speeds determined by The Aerospace Corporation during the post-event analysis were from 9 to 11 m/s. Figure 4-6 gives the air temperature versus altitude. No inversions were present.

4.5.2.4 Taggant Gas Results. The Aerospace Corporation sidelooking spectrometer in the TopKick vehicle measured a peak SF_6 column density of more than 16 ppm-m at 5.2 min after the detonation (Herr *et al.* 1997c). At the same time the Ram Van spectrometer measured a peak SF_6 column density of 9 ppm-m. The uplooking spectrometer in the Tonka vehicle measured a maximum vertical SF_6 column density of 0.25 ppm-m during the intercept beginning 46 min after the detonation. This reading was obtained during post-event analysis; the signal-to-noise ratio was too poor for real-time detection. The peak SF_6 concentration at ground level measured by the gas chromatograph during the same intercept was 122 ppt. At the later intercept the peak concentration was 11 ppt.

4.5.3 Discussion.

The cloud tracking operations for event DIPOLE ORBIT 6 were similar to those encountered during event DIPOLE ORBIT 3. The real-time cloud tracking operations produced triangulated cloud positions for 50 min after the detonation. The cloud range from the structure was approximately 27 km at this time (Figure 4-20). The Tonka vehicle was successfully directed to positions where it intercepted the cloud at times from 46 to 110 min after the detonation at ranges from 30 to 65 km. As for event DIPOLE ORBIT 3, cloud intercepts using the Tonka vehicle were made after the cloud passed over the Oscura Mountains.

SECTION 5
CONCLUSIONS

The real-time cloud tracking operations were highly successful for all of the CP ACTD events. Clouds were tracked for substantial times and distances in a variety of conditions.

The ability to track the detonation clouds was strongly affected by the weather, particularly the winds, which controlled the cloud motion, and the cloud cover, which influenced the radiometric contrast between the detonation cloud and the background for the IR sensors. The weather conditions for the five events are summarized in Table 5-1. The best cloud tracking conditions occurred with clear skies and consistent wind directions. The most difficult conditions were cloudy skies and light and variable winds.

The terrain affected the ability to maintain continuous cloud tracks when the clouds encountered elevated terrain which interrupted the lines of sight of the sensors. With consistent wind directions it was possible to predict the cloud tracks beyond elevated terrain encounters with sufficient accuracy to intercept the clouds with mobile sensors.

The cloud tracking and ground sampling results for the five CP ACTD events are summarized in Table 5-2. The first line of the table gives the maximum ranges and tracking times for the real-time cloud tracking operations in the triangulation mode, which required at least two sensors with unobstructed views of the clouds. The second line gives the total acquisition time for the last sensor that maintained contact with the cloud. The third entry gives the maximum ranges and acquisition times for the mobile laboratory in two modes, without loss of the cloud track by multiple sensors and after loss of the track when the mobile laboratory was positioned using cloud path extrapolations. The next two entries give the maximum times for which cloud dimensions (height and width) were obtained. The two following entries give the maximum ranges at which returns were obtained for aerosol samples captured by ground based samplers. The last entry describes the ability to obtain cloud edges from the ground sampler data.

Table 5-1. Weather conditions summary for CP ACTD events.

CP ACTD Event	Weather	Wind: Near Surface Speed	Wind: Direction	General Tracking Conditions
DIPOLE ORBIT 1	Clear	2-3 m/s	335° Consistent	Excellent
DIPOLE ORBIT 5	Clear	1-3 m/s	Variable	Satisfactory
DIPOLE EAST 159	Cloudy	1-3 m/s	Variable	Poor
DIPOLE ORBIT 3	Partly Cloudy	12-13 m/s	226° Consistent	Satisfactory
DIPOLE ORBIT 6	Partly Cloudy	10-13 m/s	224° Consistent	Satisfactory

Table 5-2. Cloud tracking and ground sampling results for CP ACTD events.

Tracking/Sampling Performance Parameter	Maximum Ranges from Structures and Times after Detonation									
	DO 1		DO 5		DE 159		DO 3		DO 6	
	R, km	t, min	R, km	t, min	R, km	t, min	R, km	t, min	R, km	t, min
Continuous track-multiple sensors	13	55	2	35	8	105	18	25	27	50
Continuous track-1 sensor	20	90						31		
Intercept by mobile laboratory										
Without loss of track	13	60								
After loss of track			8	63	30	229	80	190	65	110
	Maximum Time for Data Parameter									
	t, min		t, min		t, min		t, min		t, min	
Cloud height	35		10		3.5		11		34	
Cloud width	50		9		3.5		11		36	
	Maximum Range for Data Parameter									
	R, km		R, km		R, km		R, km			
Biological simulant	58				32		7			
Rare earth tracer	58				32		7			
Cloud edges from ground sampling	No		No		No		Both edges at 1 km One edge at 6 km			

For event DIPOLE ORBIT 1, the triangulated track was lost as the cloud crossed over Mockingbird Gap at a range of 15 km and a time after the detonation of 75 min. One sensor, which could view the top of the cloud, continued to report the cloud azimuth to 90 min after the detonation. Additional real-time cloud acquisitions were reported by two sensors which relocated south of Mockingbird Gap; however, these could not be confirmed during post-event analyses. The mobile laboratory did not reacquire the cloud beyond the end of the real-time track. Cloud height and width data were reported for most of the time span of the real-time track. Cloud tracking operations personnel were able to extrapolate the cloud track after loss of acquisition sufficiently accurately to permit the capture of ground samples at ranges of 28 and 58 km, well beyond the range of the real-time cloud track. Many of these samples contained measurable amounts of biological simulant and rare earth tracer. The edges of the cloud could not be determined from the ground sampling results.

The light and variable winds present during the DIPOLE ORBIT 5 event produced a completely different cloud-tracking scenario. The DIPOLE ORBIT 5 cloud dissipated rapidly and moved slowly in a generally eastward direction, causing some difficulty in tracking. The triangulated track was lost at a range of about 2 km and a time after the detonation of 35 min. Cloud tracking operations personnel were able to direct the mobile laboratory sufficiently accurately to permit cloud intercepts at ranges to 8 km and times to 63 min, well beyond the range and time of the real-time cloud track. The visible (dust) cloud top was much higher than the IR (SF_6) cloud top. This result suggested that the SF_6 was released from the structure later than the dust cloud as a result of the below ground position of the weapon. The analysis of the ground sampler results gave a direction of cloud travel nearly opposite to that determined by the mobile laboratory.

The DIPOLE EAST 159 detonation cloud was tracked in real time to a range of approximately 8 km at a time of 105 min after the detonation. The mobile laboratory intercepted the cloud at ranges as great as 30 km from the structure 229 min after the detonation. Measured biological simulant and rare earth tracer was obtained along an extended path approximately 30 km north of the structure, indicating that the cloud was very large at this distance. This was probably a result of the variable nature of the winds observed with instrumentation near the structure. Cloud dimensions, obtained from post-event analysis of the IR sensor records, were available for a relatively short time compared to the total tracking time. This and other results of the post-event analysis suggested that the techniques employed by the IR sensor operators substantially increased their ability to track the cloud in real time compared to analysis of the sensor records.

The cloud tracking operations for event DIPOLE ORBIT 3 were the first conducted during high wind speed conditions. The real-time cloud tracking operations produced triangulated cloud positions at a range of 18 km at 25 min after the detonation. The mobile laboratory was successfully directed to positions where it intercepted the cloud at ranges to 80 km and times to 190 min after the detonation, after the cloud had passed over the Oscura Mountains. This accomplishment conclusively demonstrated that the cloud could be reacquired by positioning the sensors using the predictive tools, wind measurements, and the initial real-time cloud track. Cloud dimensions were available for 11 min after the detonation. The cloud path determined from the measured biological simulant and rare earth tracers was in excellent agreement with the real-time track and cloud edges were determined for the first time using the ground samplers.

The cloud tracking operations for event DIPOLE ORBIT 6 were similar to those encountered during event DIPOLE ORBIT 3. The real-time cloud tracking operations produced triangulated cloud positions to a range of 27 km at 50 min after the detonation. The mobile laboratory was successfully directed to positions where it intercepted the cloud at ranges to 65 km and times to 110 min after the detonation after the cloud passed over the Oscura Mountains. Cloud dimensions were available for about 35 min after the detonation. No ground sampling operations were conducted for this event.

Overall, the cloud tracking operations for the CP ACTD events showed that detonation clouds could be tracked for distances as great as 27 km and times after the detonation as great as 105 min using IR sensors with SF_6 as a gaseous taggant. These sensors provided triangulated results for cloud position and dimensions for 2-5 times as long as the visible sensors (video and film cameras), which tracked the visible (dust) cloud. The lidars, which tracked the dust cloud, demonstrated their ability to obtain cloud azimuths, ranges, and dimensions independent of the optical sensors for a distance of 7.5 km and time after the detonation of 35 min, about 1.5 times as long as the video and film cameras. When wind directions were consistent for periods of several hours cloud tracking operations personnel were able to predict the cloud paths, using the predictive tools, wind measurements, and the initial real-time cloud track, sufficiently accurately to successfully direct the mobile laboratory to cloud intercepts at ranges as great as 80 km from the structure.

SECTION 6
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