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TITLE

THE DRES LARGE-SCALE FUEL-AIR EXPLOSIVES TESTING FACILITY

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THE DRES LARGE-SCALE FUEL-AIR EXPLOSIVES TESTING FACILITY (U)

by

J. Funk and S.B. Murray

Project No. 27C10

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ABSTRACT

The large-scale fuel-air explosives (FAE) testing facility, designed and built on the experimental range of the Defence Research Establishment Suffield (DRES) in 1981, is described in some detail.

Design considerations to maximize versatility, survivability of permanent operational systems, safety and diagnostic capabilities, and to minimize turnaround time for each experiment, are discussed.

Details about the concrete test bed and important operational systems of the facility, including the gas delivery, mixing and analysis systems and the initiation system, are presented. Diagnostic capabilities to monitor the outcome of each test are described, as are operational procedures for carrying out an experiment.

To date experiments involving up to 110 cubic meters of detonable mixture have been conducted. Improvements to the facility, evolving from these tests, are summarized.

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ACKNOWLEDGEMENTS

The authors would sincerely like to acknowledge the efforts of several DRES groups as well as the assistance of several individuals involved in the design and construction of the DRES FAE testing facility.

The Field Operations Section was responsible for the primary construction of the facility. The Experimental Model Shop manufactured the steel manifolds and associated fittings. The Electronic Design and Instrumentation Group provided the instrumentation expertise and design. Steve Ward, Morrie Kirschenblatt and Richard Tarnasky were all instrumental in the detail construction of the FAE testing facility.

LIST OF FIGURES

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1. INTRODUCTION

When the fuel-air explosives (FAE) research program began at DRES in 1980 the need for an adequate large-scale testing facility was realized. The planning and design for this facility was completed in the spring of 1981 and the construction was completed during that summer. The facility has been actively used for experimentation since August of 1981. The work was carried out under PCN 27C10.

The testing facility was designed in an attempt to satisfy future DRES FAE experimental field requirements. The following criteria were considered to be general guidelines for the design of the experimental layout:

i) **Versatility** — The facility must be capable of being modified quickly and easily for future, as yet undefined, FAE experiments.

ii) **Accuracy** — FAE experiments depend heavily on accurate determination of fuel and other component concentrations. Therefore, the facility must incorporate very accurate sampling and gas analysis systems. Likewise, appropriate diagnostic systems must be employed in order to adequately determine the outcome of each experiment.

iii) **Survivability** — Owing to the destructive nature of FAE testing, structures, equipment and instrumentation subjected to blast loading must be structurally hardened to ensure their survival.

iv) **Rapid Turnover** — The nature of most FAE studies require that several trials be conducted to obtain each valid data point or to examine phenomena. Minimizing the duration of the experiment as well as preparation time is therefore essential for the judicious use of the relatively short experimental period our Canadian weather permits.

v) **Safety** — Because of hazards associated with the handling and detonation of FAE mixtures, the safety of personnel must be an important consideration.

In more physical terms, the facility must have a hard level surface upon which apparatus can be mounted. It must also be capable of supplying fuel and other gases to the experimental volume, mixing these gases homogeneously throughout, and determining species concentrations accurately. In addition, the facility must have a firing system to initiate detonation of the gaseous mixture once the intended composition is reached. This firing system must be capable of coordinating the operation of high-speed diagnostic systems for data collection.

The body of this report describes in detail the features of the DRES FAE facility. General layout and configuration of the test pad is outlined in Section 2. The gas delivery, mixing and analysis systems are described in Sections 3, 4 and 5, respectively. Initiation system details are given in Section 6. Diagnostic capabilities are discussed in Section 7. Finally, safety considerations and concluding remarks appear in Sections 8 and 9.

2. CONCRETE TEST PAD

The FAE testing facility is centered around a concrete test pad. The pad is 18.3 m long × 7.6 m wide × 0.3 m thick and is heavily reinforced to withstand severe shock loading. The surface of the pad incorporates a 1% grade to facilitate water drainage. Imbedded in the surface of the test pad are seven mounting channels which are oriented longitudinally along the entire length of the pad and welded firmly to the steel reinforcing grid. These mounting channels, illustrated in Figures 1 and 2, together with 18 mm diameter T-bolts, allow various types of experimental apparatus to be mounted securely to the test pad with ease. They also serve as trays for instrumentation cables, allowing ready access to the cables while keeping them protected.

The longitudinal axis of the test pad runs parallel to the direction of the prevailing wind. This is an important consideration since many of the planned FAE tests involve large surfaces of polyethylene which are very susceptible to damage from cross winds.

Photographs of the test pad appear in Figure 3.

3. GAS DELIVERY SYSTEM

The gas delivery system is designed around three "Matheson®" mass flow controllers; two having a maximum flow rate of 100 standard liters per/minute (SLPM) and the third having a capacity of 400 SLPM. See the schematic in Figure 4. Each controller can be used to regulate a variety of gases by applying a constant correction factor to the calibration curve for a specific gas.

The setpoint controls and digital readout for each mass flow controller are located inside the fuel-control bunker. High-pressure commercially bottled gases are reduced in pressure via dual-stage regulators before passing through solenoid shut-off valves and the mass flow controllers. For tests involving large volumes of gas it is possible to manifold several bottles together.

These gases are then piped 50 m to the test pad through three lines, one of 18 mm diameter and two of 13 mm diameter. In addition to the flow of fuel through one line, the other two can be used to flow diluent, oxidizer, sensitizer, or to flow components of a detonation-sensitive mixture for the purpose of ignition. Knowing the volume of the test apparatus, it is a simple matter to calculate the amount of each gas needed to bring the experimental mixture to a specified state.

4. GAS CIRCULATION SYSTEM

Once gases have been introduced into the experimental volume it is essential that they be mixed homogeneously with the initial air. Although diffusion can be used to achieve homogeneity this process takes considerable time in large-scale experiments. The DRES facility makes use of a multipath recirculation system to mix the experimental gases. A high capacity blower, shown in Figure 5, is connected between two 300 mm diameter steel manifolds buried underground along the length of the test pad. This assembly has eight 100 mm diameter outlets, four located upstream of the blower (low-pressure side) and four located downstream (high pressure side) as illustrated in Figure 6. Any one of four 100 mm diameter steel headers can be attached to any of these eight outlets to evenly distribute the flow to various points in the test section. These headers are equipped with 100 mm diameter remotely-actuated butterfly valves which can be used to either regulate or shut off the flow. Each header extends to the center of the test pad and is connected to the test apparatus with a short length of flexible plastic hose. The manifold assembly is also fitted with two 40 mm solenoid shut-off valves located at the upstream and downstream ends. These valves open the manifolds to atmosphere and are used for purging purposes.

A 12 mm solenoid shut-off valve is located just upstream of the blower. It is open to atmosphere during an experiment in order to maintain the pressure of the system above atmospheric pressure. Since polyethylene bags are often part of the experimental apparatus, this overpressure is useful in keeping the bag inflated. In this state it is less susceptible to damage by wind. Small leaks in the polyethylene or at sealed joints would cause the bag to deflate if this pressure control valve did not allow additional air to enter to compensate for the losses.

The centrifugal blower employed has a capacity of over 20 cubic meters per minute at 100 mm H_2O static head. It is equipped with an explosion-proof electric motor, a stuffing box to seal in explosive gases, and an aluminum rotor wheel to eliminate any sparks that could ignite the detonable gases being circulated.

During a typical experiment all butterfly valves are left open to maximize circulation. When very thin polyethylene bags are used, however, the two downstream valves are partially closed to avoid overinflating the bag. The pressure control valve is also left open to ensure adequate inflation. Once the proper mixture composition has been reached the pressure control valve is closed. After this point in time the mixture maintains a fixed composition until firing. With this valve closed, however, small leaks begin to decrease the pressure in the bag. As this pressure approaches atmospheric pressure the bag becomes more susceptible to destruction by winds. In this light it is best to leave the pressure control valve open until shortly (less than 10 minutes) before firing. The small leak rate in question is, in fact, beneficial in attaining the desired mixture composition. During a typical experiment a rich mixture is created in the test section which is subsequently allowed to "leak" down to the desired composition at a slow rate.

Two minutes before firing the two butterfly valves upstream of the blower are closed and the upstream purge valve is opened. This allows a slug of correct mixture in the manifold to repressurize the bag in preparation for firing. This is accomplished in a few seconds. Subsequently, the downstream butterfly valves are closed and the downstream purge valve is opened, thereby isolating the experimental volume while purging the manifolds and blower with air. This eliminates the possibility of flashback through the blower which could be catastrophic.

5. GAS ANALYSIS SYSTEM

The most crucial and difficult experimental parameter to measure in gaseous explosive testing is the concentration of a particular species in the mixture. In the foreseeable future the species of interest will always be some form of hydrocarbon in a gaseous state. For this reason it was decided to employ infra-red real-time gas analysis.

The core of the analysis system is a "Wilks Miran 80®" infra-red gas analyzer which is capable of multi gas analysis. Since the analyzer is a sensitive instrument it is housed in the fuel-control bunker 50 m from the test pad. It receives gas samples on a continuous basis from four locations in the test section, as shown in the schematic of Figure 7.

In order to avoid contamination of the gas samples while flowing between the test pad and bunker the sampling network was designed to operate above atmospheric pressure throughout, thereby eliminating errors caused by small leaks in the sampling lines. For this reason gas sampling pumps (to drive the sample gas around the sampling circuit) were mounted at the edge of the test pad. Since the mixture in the experimental volume is normally somewhat above atmospheric pressure the short feed lines from the test section to the pumps are maintained above atmospheric pressure as well.

The pumps used are "Webster®" diaphragm compressor pumps having a capacity of 30 liters per/minute. This capacity was chosen to accommodate the gas analyzer which has a 5.6 liter test chamber. Assuming five gas changes are needed to purge the analyzer of the previous sample, a cycle time of about one minute is possible. Since the flow rate of sample gas is high it is returned to the experimental volume to avoid undesirable reduction in concentration by removal of such large quantities for analysis purposes.

The system of solenoid valves shown in Figure 4 was developed to facilitate automatic sampling from up to four individual sample locations. An electronic programmer automatically controls sample sequencing. Although the programmer is completely automatic, trial personnel have complete manual override on all valves.

During a normal sampling sequence the programmer first opens one of the four selection valves as well as both isolation valves (located on either side of the analyzer) for a time corresponding to the purge time of the analyzer. Positive flow is ensured by check valves. Once the analyzer has been purged the programmer closes the selection valve as well as both isolation valves. Since infra-red gas analysis is sensitive to pressure a bleed valve is opened at this time to vent the sample to atmosphere. The programmer then initiates the gas analysis routine. Once the routine has been completed the entire sequence begins again with another selection valve (corresponding to another sampling location). The system presently uses a two minute cycle time per sampling line. After homogeneity of the gas mixture throughout the apparatus has been established all four sampling lines may be accessed simultaneously so that the analyzer purge time is reduced.

As mentioned above, the analysis is sensitive to the pressure of the gas sample. The correction factor is calculated by obtaining the ratio of absolute calibration gas pressure to absolute sample gas pressure. Since the bleed valve ensures that the sample is at atmospheric pressure the correction factor becomes the ratio of calibration gas pressure to atmospheric pressure, which are both monitored throughout the course of each experiment.

The gas analysis is also sensitive to sample gas temperature. A thermocouple is used to measure sample gas temperature. The correction factor is then calculated as the ratio of sample gas temperature to calibration gas temperature. These correction factors are immediately applied to the analyzer infra-red absorbance readings. Prior to daily use, the analyzer is calibrated using both commercially and internally prepared gas samples. A plot of ethylene concentration versus time for a complete experiment is shown in Figure 8. The downward trend in concentration after the peak is due to small leaks at sealed joints and in the polyethylene material used in this experiment. As noted previously, these small leaks actually provide a method of reducing the fuel concentration by small amounts until the desired concentration is reached. The pressure control solenoid valve (see Gas Circulation System) is then closed, thereby holding the composition constant until firing.

Before firing, the analyzer is purged with air and then isolated from the sampling system with manual valves to eliminate any possibility of flashbacks damaging the analyzer.

To independently verify the gas analysis a sample is trapped in a 250 cc gas sampling tube about one minute before firing and taken back to the laboratory where it is further analyzed by gas chromotography and mass spectrometry.

6. INITIATION SYSTEM

Once the proper gas composition has been achieved some method of initiation must be employed to detonate the mixture.

The DRES initiation system centers around a timing and firing sequencer. This sequencer incorporates a 15 second countdown before firing and a 15 second count after firing. The countdown clock is used to start high-speed cameras, high-speed tape recorders, and charge a 1 micro-farad capacitor at various preset times before the instant of firing.

At time zero this capacitor, charged to 3,000 volts, is discharged through the firing lines. The energy pulse fires an exploding bridgewire Reynolds detonator which initiates a variable amount of solid explosive (PETN). The blast wave from this explosion in turn initiates the gaseous mixture directly. The capacitor discharge is also suffient to initiate a slug of detonation-sensitive gas with an exploding wire. Once detonation is established in the sensitive slug it transmits to the mixture being studied. At time zero the sequencer also produces a trigger signal which can either be used to activate instrumentation or be stored on a tape track for simplification of data reduction. After the firing pulse the sequencer continues counting for an additional 15 seconds, turning off equipment and returning the firing circuit to a safe condition.

7. DIAGNOSTIC SYSTEMS

The DRES FAE testing facility was designed to be as flexible as possible regarding diagnostic methods. See Figure 9. The test pad and instrumentation van are presently connected by 55 low-noise, underground cables (20 coaxial and 35 shielded twisted pairs). Sufficient cable has been installed to accommodate an expansion to 85 channels. Junction boxes are located both at the test pad and at the instrumentation van. This allows virtually any type of electronic instrumentation to be used with a minimum of modification or additional cable.

At present, electronic instrumentation consists of twelve piezoelectric pressure transducers and 20 ionization probes. The pressure transducers are mounted at various locations for different FAE tests. Eight transducers (PCB 113A24) are mounted directly in the experimental test section to measure the pressure-time history of the detonation wave. The remaining four pressure transducers (PCB and Kistler) are mounted in specially designed, portable, far-field gauge stands which can be moved easily around the layout up to a distance of 75 meters from the test pad. A typical gauge stand is shown on the extreme right of the lower photograph of Figure 3. These transducers measure far-field blast wave overpressure signatures which are recorded on a multichannel high-speed tape recording system. Honeywell, Ampex and Racal recording systems are available with frequency responses up to ~200 KHz. Hard copy reproduction of the pressure records can be made immediately by an oscillograph, on site, for qualitative analysis. The tape can also be digitized for quantitative computer analysis at a later date.

The ionization probes are connected to a 20-channel power supply and electronic counter which were designed and built at DRES. All channels begin counting at arrival of the firing or "det zero" pulse. As the detonation wave passes over each ionization probe, it ionizes the gas between the probe electrodes, lowering the path resistance. This is sensed by the probe unit which in turn stops the count of individual channels. Each channel then has an elapsed time from det zero, which can be used to determine velocity knowing the location of each probe. Probes can be situated strategically along the experimental test section to give an appropriate velocity profile.

Apart from electronic diagnostics, the DRES facility is capable of operating three high-speed cameras simultaneously with the option of locating the cameras at any of six different locations. Additional positions can be added quickly, if necessary. At present the photographic data collection is done by a "Hycam®" 16 mm high-speed camera operating at up to 20,000 half frames per/second and a "Fastax®" 16 mm high-speed camera operating at up to 5,000 full frames per/second. These cameras are started by the timing and firing sequencer at prescribed times before det zero to allow them to accelerate up to speed.

In addition to electronic and photographic diagnostic systems, "smoked" foils are used to yield information about detonation wave structure. A thin metal sheet is smoked with a light layer of carbon black and fastened to the walls of the test section. The passing detonation wave "writes" on the smoked foil, leaving behind a record of the wave structure.

8. SAFETY CONSIDERATIONS

FAE testing involves extensive handling of flammable or detonable gas mixtures which can pose a serious hazard to personnel in the vicinity of the experimental layout. To minimize the possibility of accident during an experiment, air only is used to inflate the collapsible polyethylene bag or tube; also, the ignition end of each experimental configuration is fitted with high explosives (for initiation purposes) while air only is contained within the test section. Before gas is flowed all personnel must be inside either one of two protective bunkers located 50 meters from the test pad. All experimental operations can be controlled remotely from inside these bunkers. See Figure 10.

The gas analyzer contains the only test gas permitted inside the bunker. Its analysis chamber, which is capable of withstanding 10 atmospheres overpressure, is purged with air before firing to eliminate the possibility of a flashback inside the bunker. All sampling lines are equipped with flame arrestors.

9. CONCLUDING REMARKS

Since the completion of the testing facility, over 80 tests have been carried out. These tests involved polyethylene tubes with diameters ranging from .89 meter to 3.66 meters, in conjunction with steel tubes having diameters of 0.3 to 1.83 meters. Throughout the tests the facility has demonstrated its flexibility, reliability and safety, with only a few minor modifications being required.

The mass flow controllers were limited in their application to only achieving approximate fuel concentrations due to a significant temperature effect on their performance.

All other systems operated reliably without damage or failure throughout the trials. The test pad shows no blast effects and the analyzing, mixing and gas delivery systems operated very consistently throughout the trials.

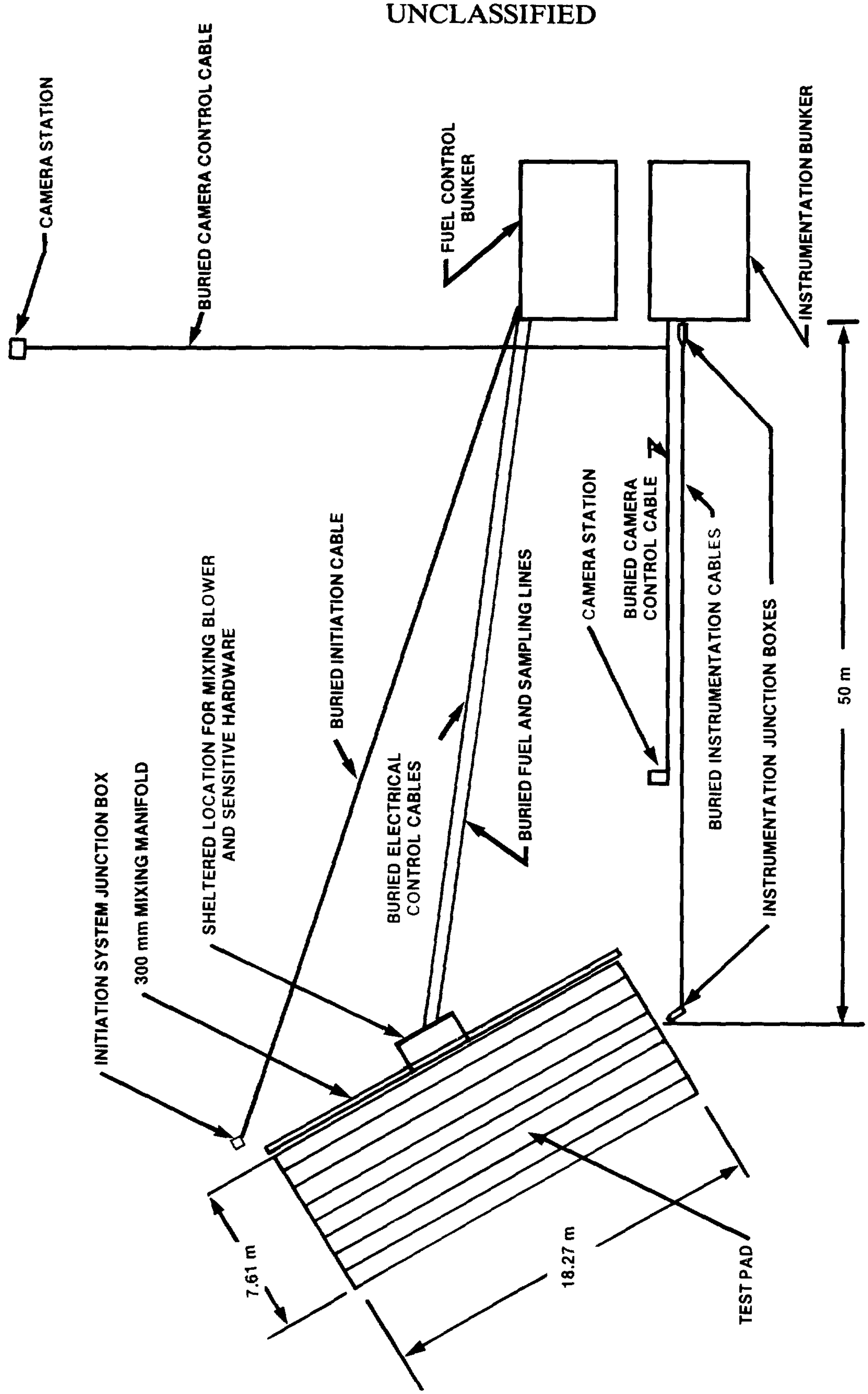


Figure 1

PLAN VIEW OF THE DRES FAE FACILITY

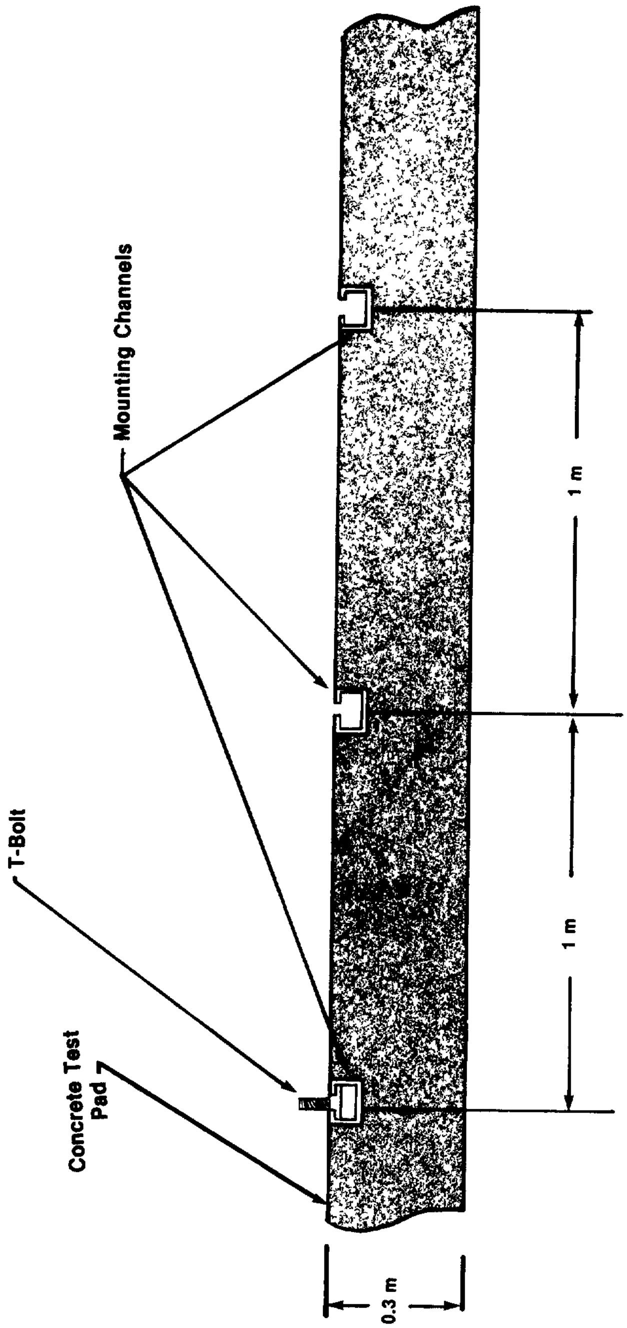
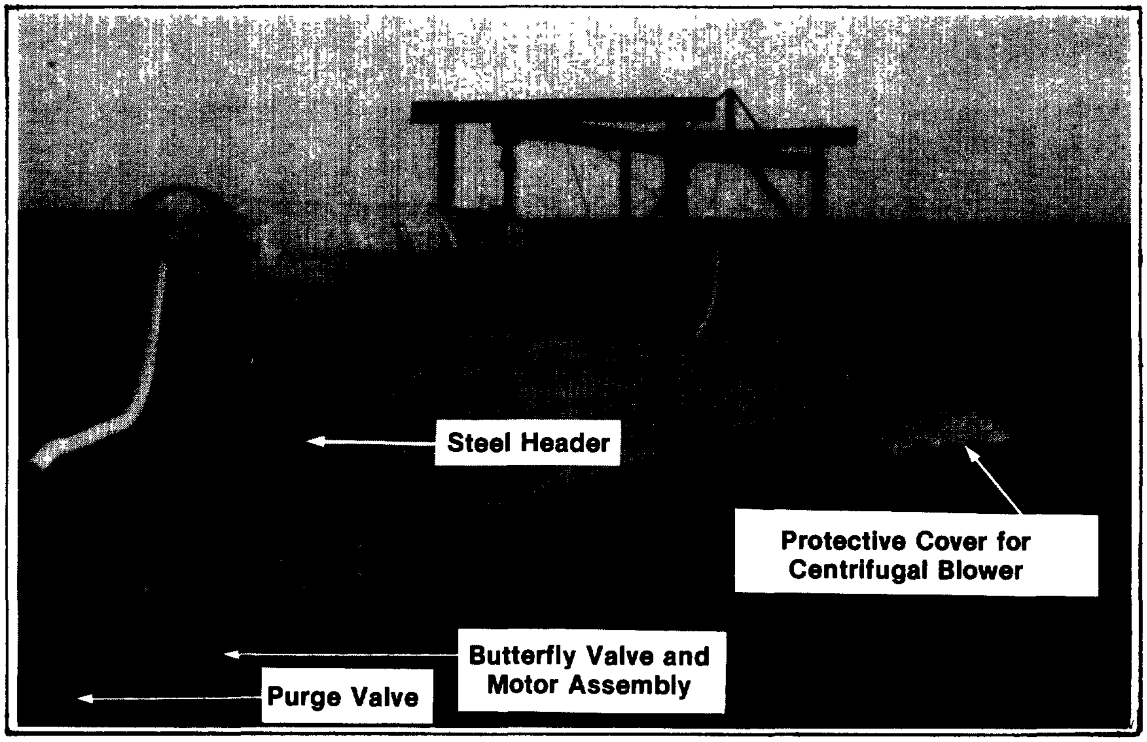


Figure 2
MOUNTING CHANNELS



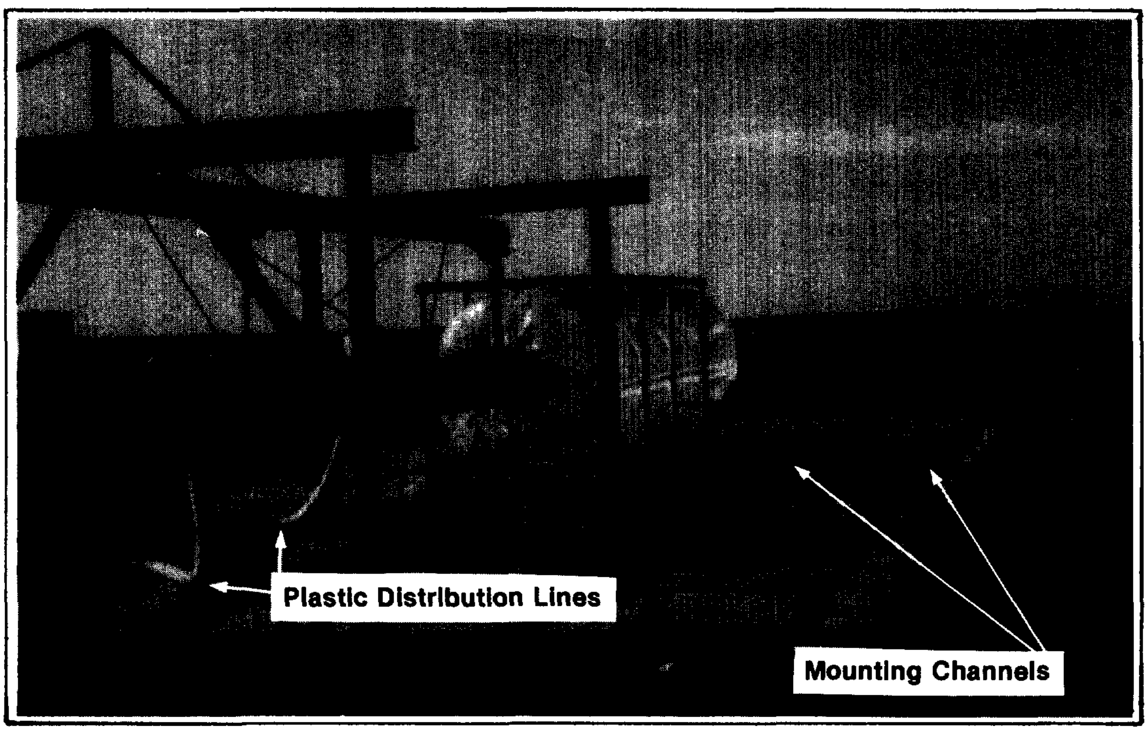


Figure 3

CONCRETE TEST PAD

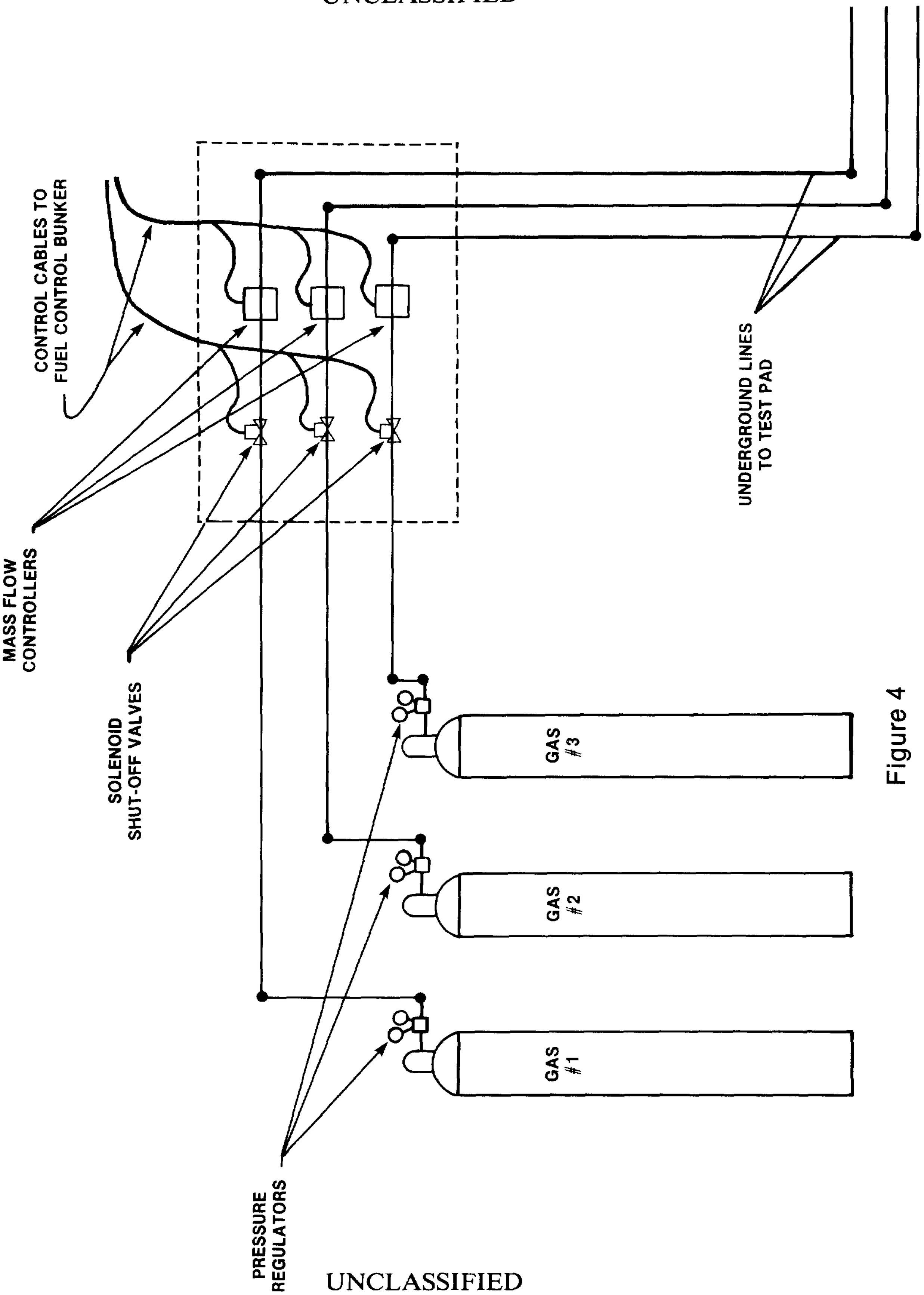


Figure 4
GAS DELIVERY SYSTEM

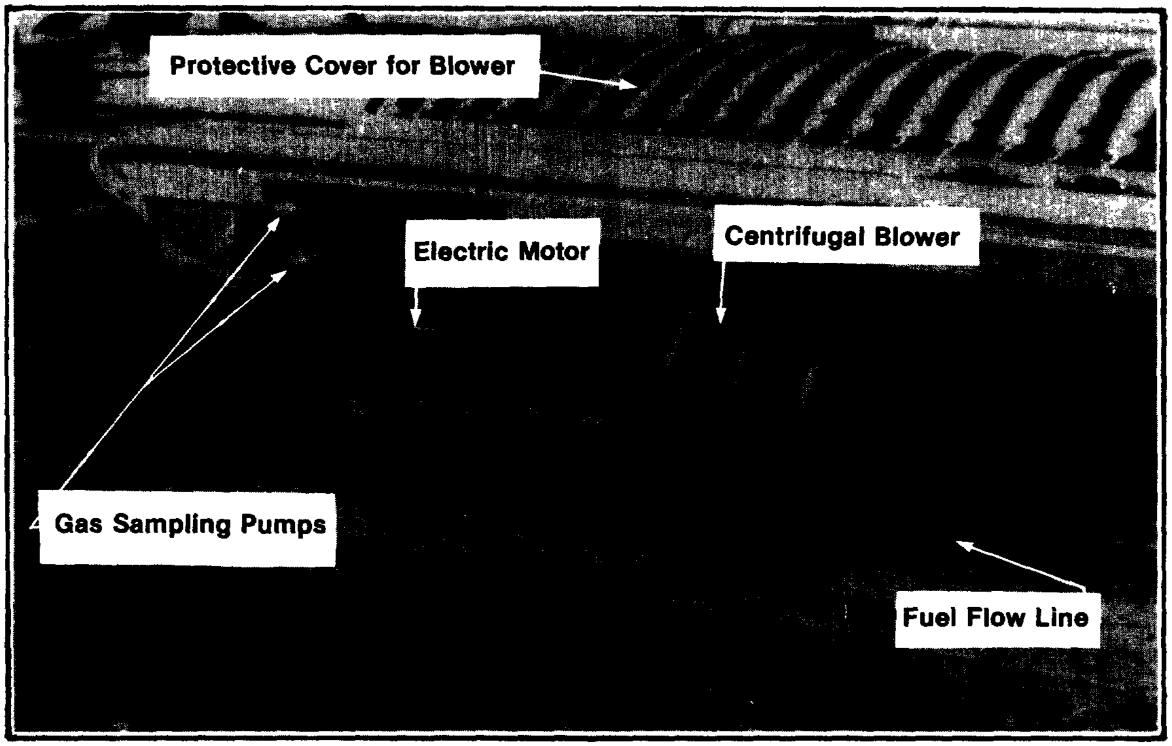


Figure 5

CENTRIFUGAL BLOWER USED FOR MIXING COMBUSTIBLE GASES

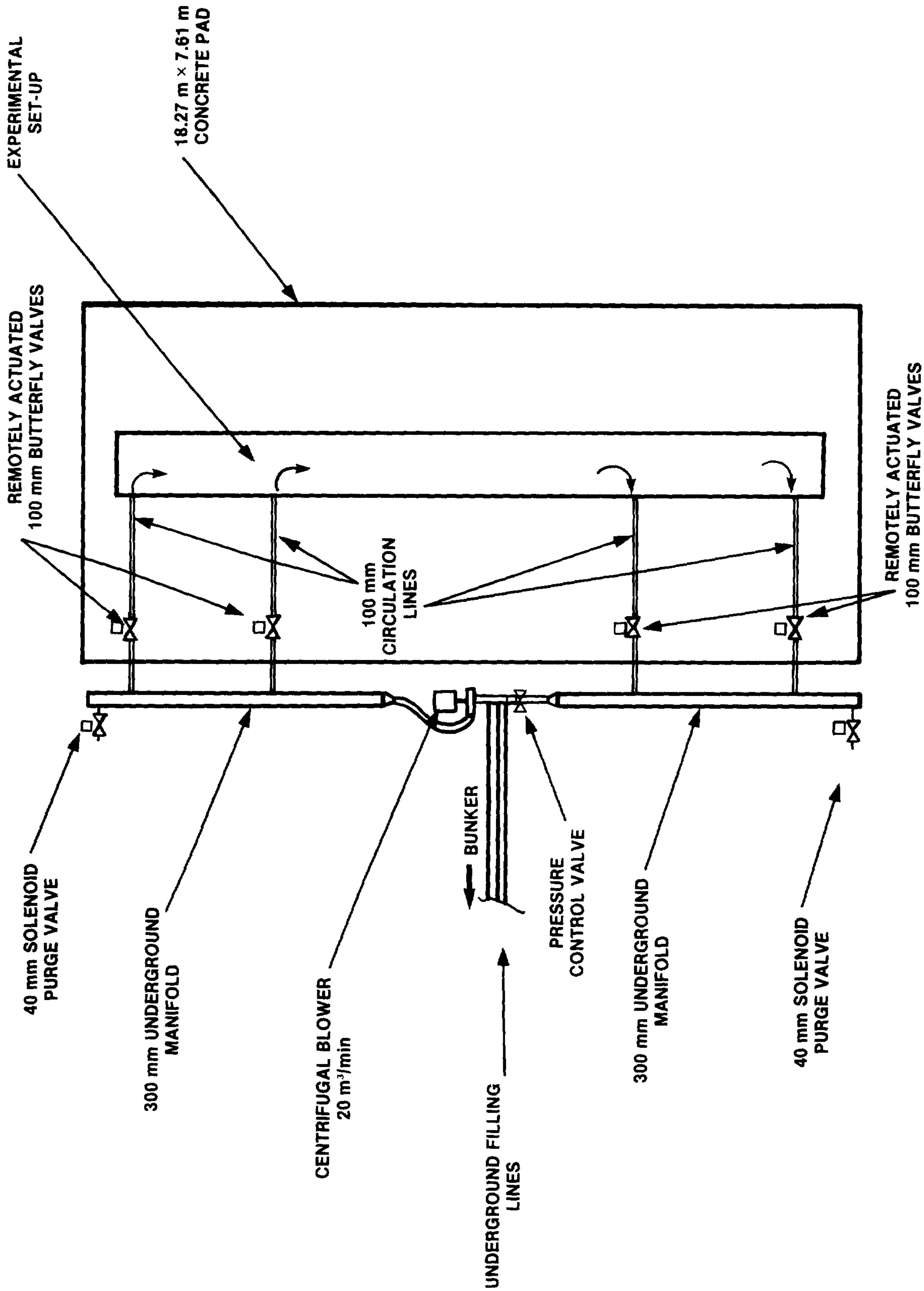


Figure 6

THE GAS MIXING SYSTEM

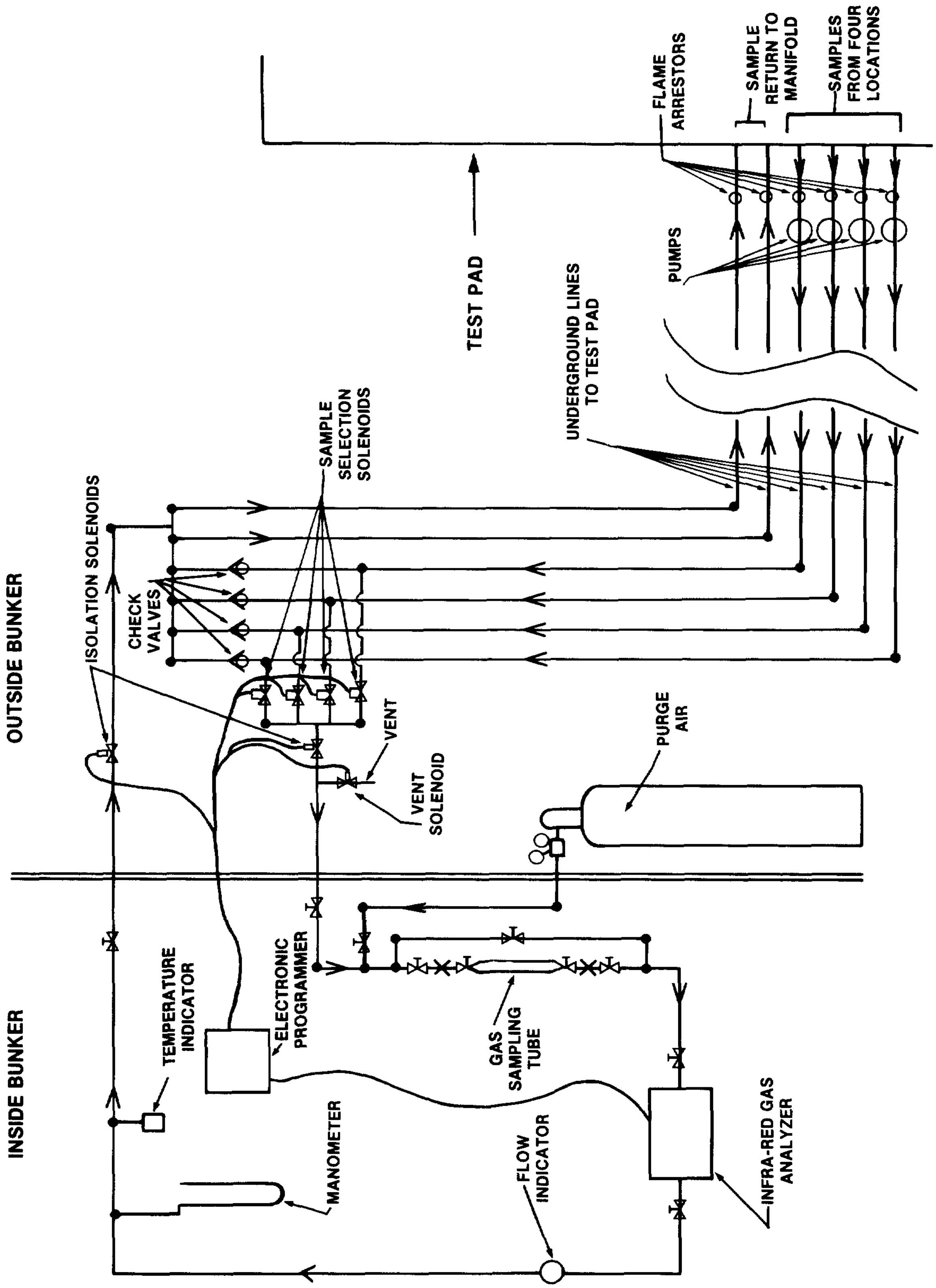
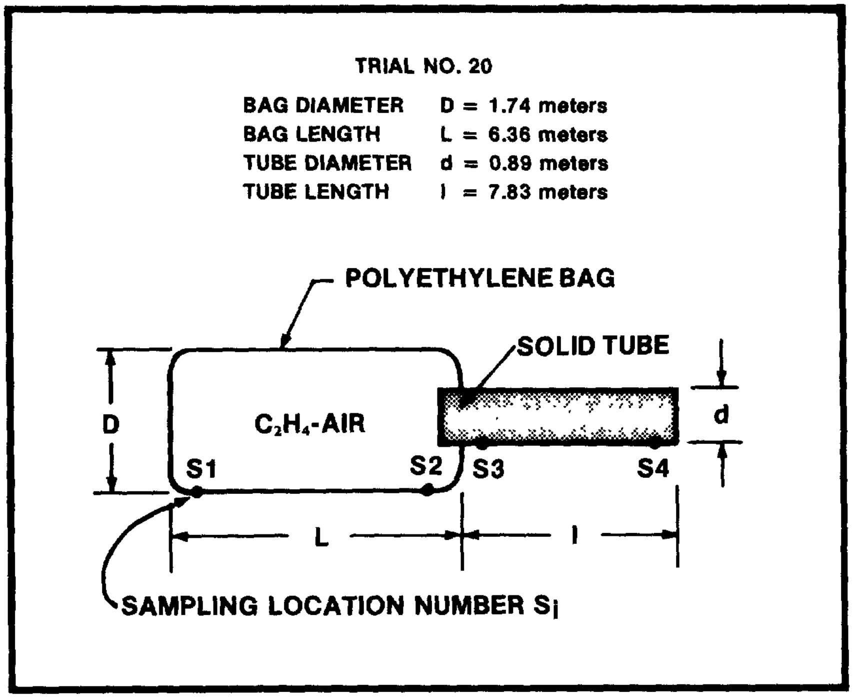


Figure 7
ANALYSING SYSTEM SCHEMATIC



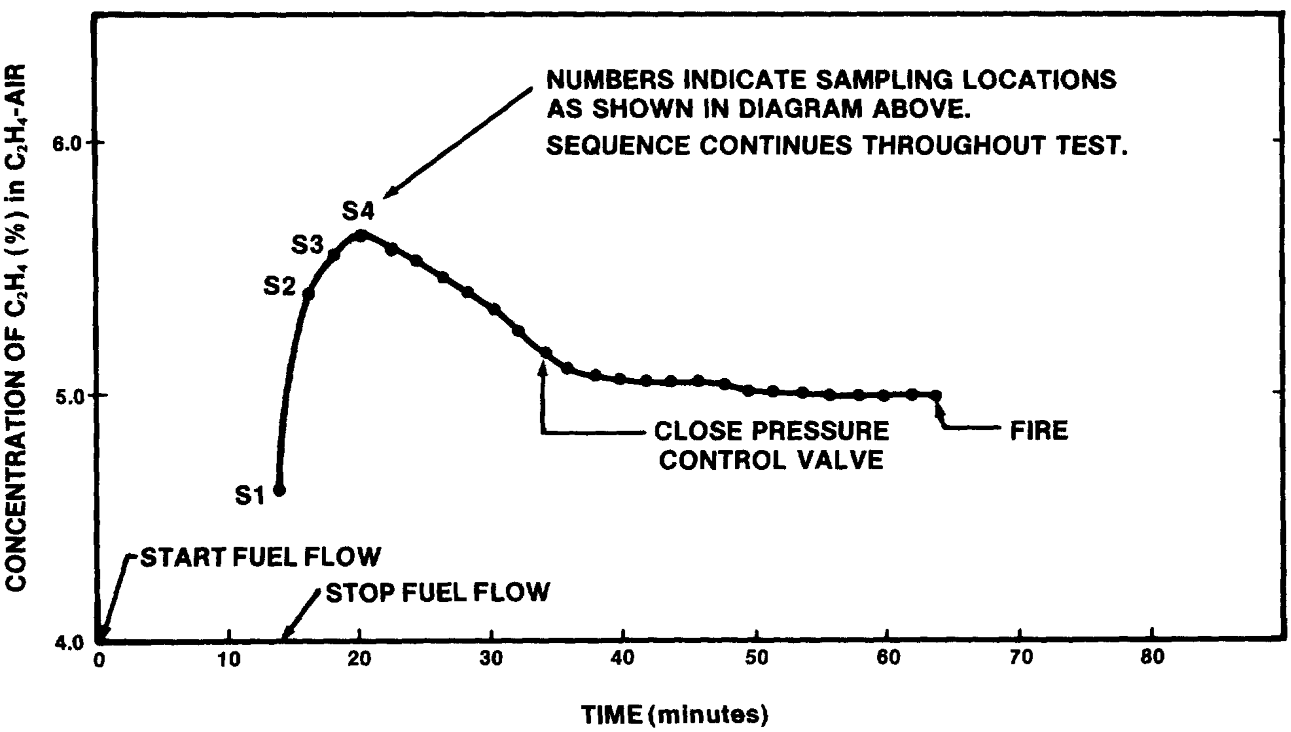


Figure 8

FUEL CONCENTRATION (% C_2H_4 IN C_2H_4-AIR) VERSUS TIME (MINUTES) FOR A TYPICAL EXPERIMENT

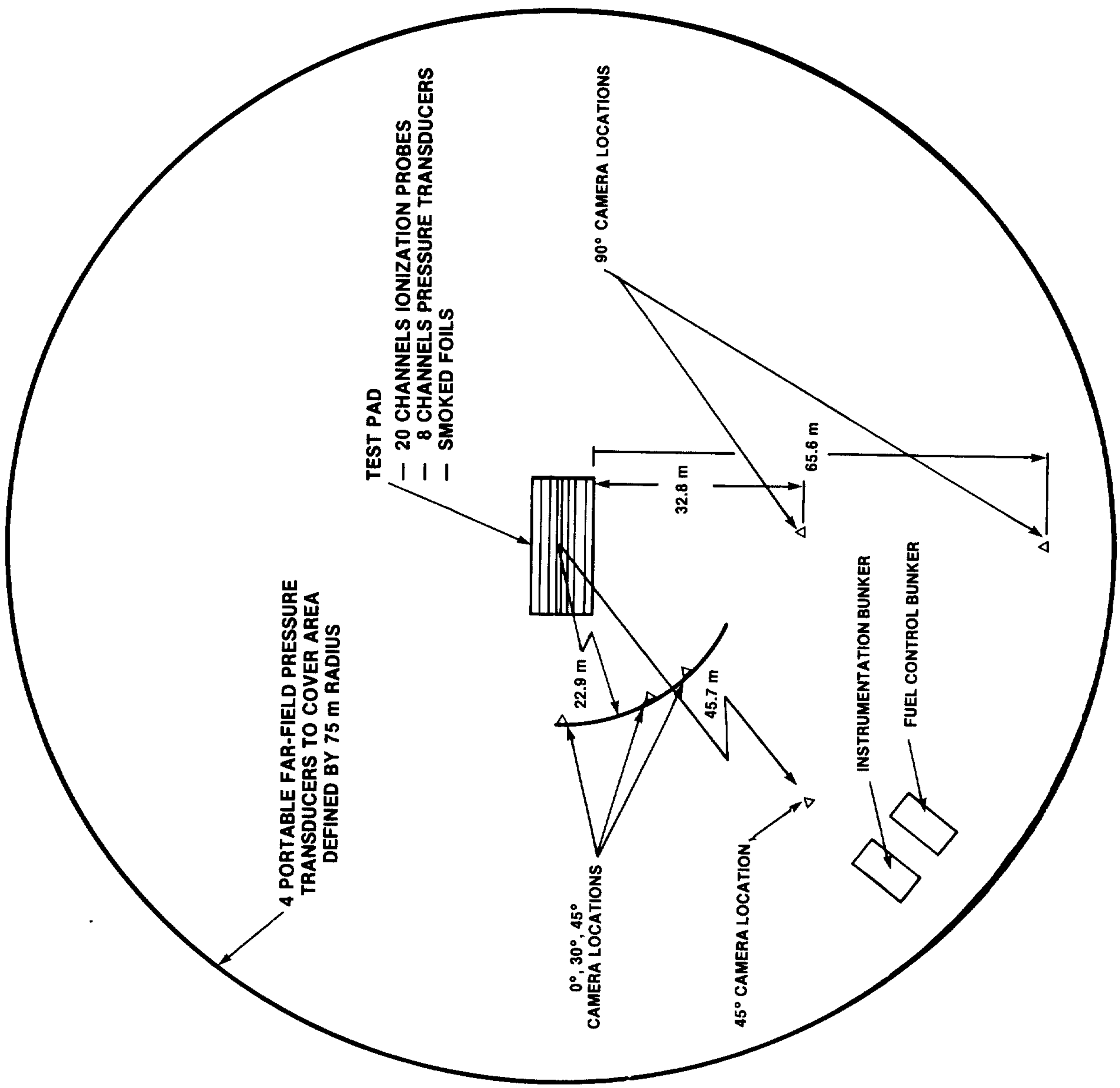


Figure 9
DIAGNOSTIC SYSTEMS

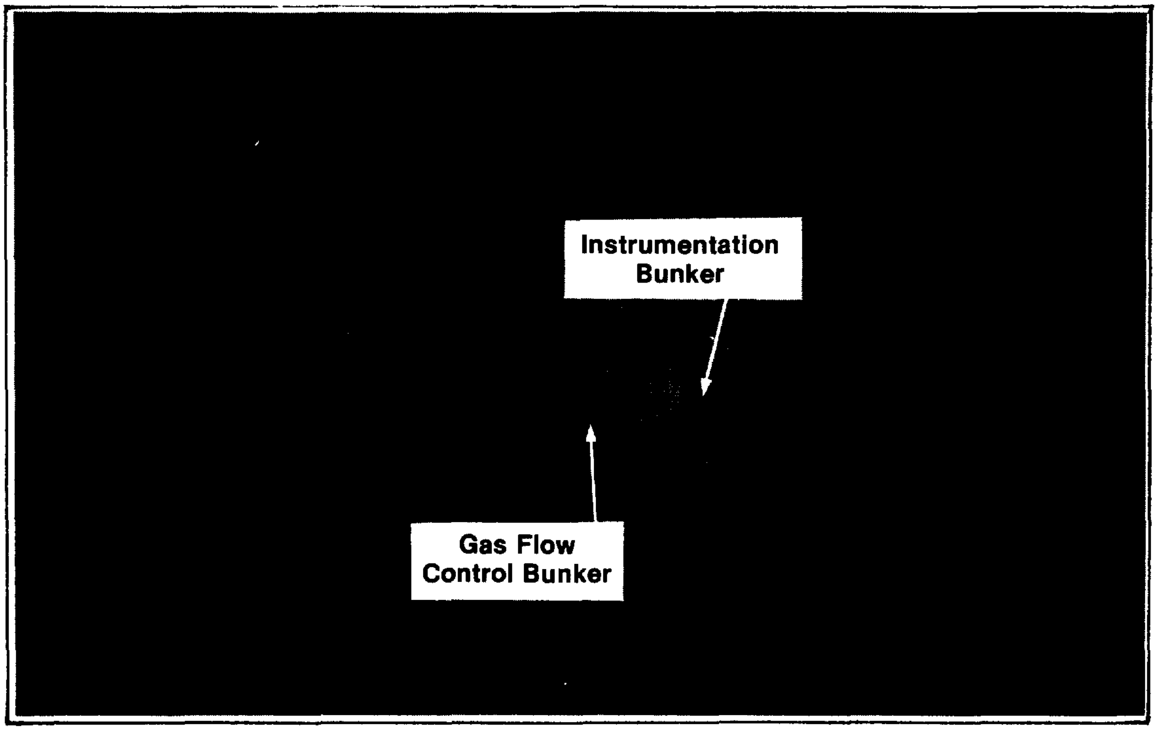


Figure 10

INSTRUMENTATION AND GAS FLOW CONTROL BUNKERS

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