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A BRIEF DESCRIPTION OF THE DRES FUEL-AIR EXPLOSIVES
TESTING FACILITY AND (U) DEFENCE RESEARCH
ESTABLISHMENT SUFFIELD RALSTON (ALBERTA)

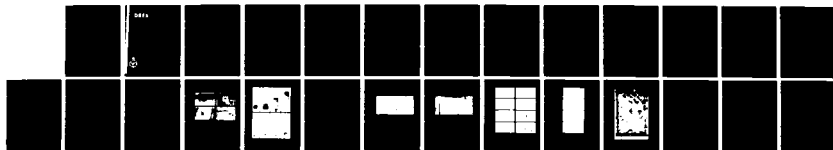
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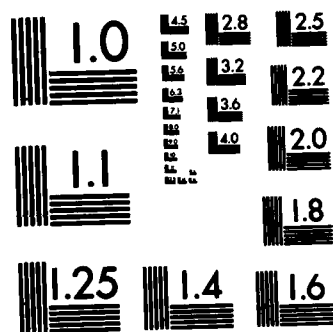
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DRES

SUFFIELD MEMORANDUM

NO. 1053

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A BRIEF DESCRIPTION OF THE DRES FUEL-AIR EXPLOSIVES TESTING FACILITY AND CURRENT RESEARCH PROGRAM* (U)

by

J.W. Funk, S.B. Murray, S. Ward and I.O. Moen

PCN 27C10

September 1982

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* Presented at the International Specialist Meeting on Fuel-Air Explosions,
McGill University, Montreal, November 4-6, 1981



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ABSTRACT

The key features of the fuel-air explosives (FAE) field testing facility at the Defence Research Establishment Suffield (DRES) are described. The current test program at DRES is focused on critical conditions for initiation and transmission of detonation in ethylene-air mixtures. This program includes an investigation of the influence of confinement on the propagation of detonation. Selected results from these investigations are discussed and typical photographic and smoked-foil records obtained during the current test program are included.

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We gratefully acknowledge the effort of management, in particular that of J. Anderson, F. Christie and B. Laidlaw, in making possible the construction of the FAE facility in such a short period of time. Many DRES groups should also be recognized for their efforts, both during the construction phase and during the FAE tests. These include the Field Operations Section, Electronic Design and Instrumentation Group, Photo Group, Experimental Model Shop, Chemistry Section and Computer Group.

We would also like to thank J. Lee of McGill University for his scientific advice and encouragement during the planning stages and analysis of results.

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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, 1981. This report describes the general features of the DRES FAE facility. A more detailed description is given in Ref. 1. General layout and configuration of the test pad is outlined in Section 2. The gas delivery, mixing and analysis systems are described in Section 3. Details of the initiation system and diagnostic capabilities are discussed in Section 4. The current research program with some preliminary results is described in Section 5, and a discussion of future plans together with concluding remarks appears in Section 6.

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2. THE TEST PAD

The FAE testing facility is centered around a reinforced concrete test pad. The test pad is 18.3 m long $\times$ 7.61 m wide $\times$ 0.36 m thick. A plan view of the facility is shown in Figure 1. The surface of the pad incorporates a 1% grade to facilitate water drainage. Imbedded in the surface of the test pad are seven longitudinal mounting channels. These channels allow various types of experimental apparatus to be mounted securely to the test pad. 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 long polyethylene bags which are susceptible to damage from cross winds.

3. THE GAS FLOW 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. Each controller can be used to regulate the flow of a variety of gases. These gases are 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 lines can be used to flow diluent, oxidizer, sensitizer, or components of a detonation-sensitive mixture used for initiation purposes. 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 composition.

Once the test gases have been introduced into the experimental test section they are mixed with the initial air by a multipath recirculation system using a high-capacity blower connected between two 300 mm diameter steel manifolds buried underground along the length of the test pad. The manifold 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 2. Any one of four 100 mm diameter steel headers can be attached to any of the eight outlets to evenly distribute the flow to various points in the test section. The headers are equipped with 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 via flexible plastic hose. The manifold assembly is also fitted with two solenoid shut-off valves located at the upstream and downstream ends. These valves open the manifold to the atmosphere and are used for purging purposes; in particular, the purging of the manifold and blower assembly prior to initiation of detonation.

The centrifugal blower employed has a capacity of more than 20 cubic meters per minute at 75 mm H₂O 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 explosive gases being circulated.

Real-time gas analysis is facilitated by a 'Wilks Miran 80' infrared gas analyzer which is capable of simultaneous multigas analysis. The analyzer is housed in the fuel control bunker 50 m from the test pad. The analyzer receives gas samples on a continuous basis from up to four locations in the test section. Gas sampling pumps used to drive the sample gas around the sampling circuit 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 between samples, a cycle time of about one minute is possible. A system of solenoid valves was developed to facilitate automatic sampling from the four individual sample locations. An electronic programmer automatically controls sample sequencing. Although the programmer is completely automatic, trial personnel have complete manual option on all valves.

A plot of ethylene concentration versus time for a complete experiment is shown in Figure 3. The downward trend in concentration after the peak is due to small leaks at joints and in the polyethylene bag used in this experiment. These small leaks actually provide a method for reducing the fuel concentration by small amounts until the desired concentration is reached. A pressure control solenoid valve 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 to eliminate any possibility of flashback damaging the analyzer.

Prior to use the infrared gas analyzer is calibrated using both commercially and locally prepared gas samples. These samples are periodically used to reconfirm the calibration. To independently verify the gas analysis a sample from each experiment, trapped in a 250 cc gas sampling bottle, is taken back to the laboratory for further analysis by gas chromatography and mass spectrometry.

4. INITIATION SYSTEM AND DIAGNOSTIC CAPABILITIES

The initiation system centers around a timing and firing sequencer. The 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 to charge a capacitor at various preset times before firing. At time zero the 8 microfarad

capacitor, charged to 2,000 volts, is discharged through the firing lines. The energy pulse fires an electric detonator which initiates detonation of a variable amount of solid explosive (PETN) for direct initiation of detonation in the gaseous mixture. The capacitor discharge is also sufficient to initiate detonation of a slug of sensitive mixture using an exploding wire. At time zero the sequencer produces a trigger signal which is used to activate instrumentation. This signal is also stored on a tape track to aid data reduction at a future time. After firing, the sequencer continues counting for an additional 15 seconds, turning off equipment and returning the firing circuit to a safe condition.

The DRES FAE testing facility was designed to be as flexible as possible regarding diagnostic methods. The test pad and instrumentation van are presently connected by 55 low-noise underground cables (20 co-axial and 35 shielded twisted pairs). Sufficient cable has been installed to accommodate up 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 minimum modifications.

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 around the layout up to a distance of 75 meters from the test pad. These transducers measure far-field blast-wave overpressure signatures. All pressure signals 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. For qualitative analysis hard copy reproduction of the pressure records can be made immediately by an oscillograph. The data can also be digitized for quantitative computer analysis at a later date.

The ionization probes are connected to a 20-channel power supply and an electronic counter 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 the gas between the probe electrodes is ionized, lowering the path resistance. This is sensed by the probe unit which in turn stops the count for that channel. Each channel therefore monitors the elapsed time from 'det zero'. These probes are situated strategically throughout the experimental test section.

Besides 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. At present, the photographic data collection is done by a 'Hycam' 16 mm high-speed camera operating at up to 20,000 frames per second and a 'Fastax' 16 mm high-speed camera operating at up to 5,000 frames per second. These cameras are started by the timing and firing sequencer at prescribed times before 'det zero' to allow cameras time 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 sheet of tin is smoked with a light layer of carbon black and fastened to the wall of the test section. The passing detonation wave 'writes' on the smoked foil, leaving a record of the wave structure.

5. CURRENT RESEARCH PROGRAM

The current DRES research program is focused on obtaining a basic understanding of the detonability properties of fuel-air explosives. Remote from physical boundaries and other perturbations, the propagation of detonations in uniform FAE clouds can be adequately described by such parameters as the detonation velocity and pressure. These parameters can be obtained from standard Chapman-Jouguet (C-J) calculations. However, from the practical point of view, one is also interested in the critical conditions for the onset of detonation in a given FAE, the influence of non-uniform fuel concentration and boundaries on the propagation of detonations and the transmission of detonation, from one cloud to another or through openings.

Two of the basic properties which characterize FAE are the critical initiation energy (E_c) and the critical tube diameter (d_c) for a confined detonation in a tube to transmit to an unconfined detonation. On the fundamental level, these properties are related to the coupling between chemical energy release and gasdynamics responsible for the three-dimensional structure of detonation waves.

Theoretical models and correlations linking the detonability properties of FAE (i.e., critical energy, critical tube diameter, characteristic transverse wave structure and chemical kinetics) have been proposed (2-5). Most of the experiments in support of these models and correlations have been limited to confined laboratory experiments. As long as the characteristic transverse wave spacing of the detonation is at least an order of magnitude smaller than the dimensions of the laboratory apparatus the influence of confinement is minimized (6). This requirement alone precludes the possibility of investigating the behavior of unconfined detonation in most fuel-air mixtures in the laboratory. The DRES FAE program was therefore designed to investigate the initiation, propagation, and transmission properties of fuel-air explosive mixtures on a scale where confinement effects do not play a role. In fact, one of the key ingredients of the program is an investigation of the influence of confinement on these properties.

A series of field tests was performed during the summer months of 1980 to determine the critical energy for the initiation of detonation of ethylene-air mixtures. The tests were performed in a plastic bag 10 m long with a cross-sectional area of $1.83 \text{ m} \times 1.83 \text{ m}$ using initiator discs of Detasheet explosive at one end of the bag. The results of these tests, which were performed prior to upgrading of the FAE facility, are described in detail in Ref. 7. Photographs illustrating the gas bag configuration for these tests are shown in Figure 4. A typical sequence from a high-speed cinematographic record showing successful initiation of detonation in the bag is included in Figure 5. In these tests the critical energies for ethylene-air compositions between 3.9% and 6.4% by volume were determined by a Go-No Go procedure. The results are summarized and compared with previous results in Figure 6. The solid curve is a correlation based on the work model proposed by Matsui and Lee (11), normalized at stoichiometric composition.

Detailed observation of the propagation of detonation in the bag indicated that the plastic bag walls began to influence the propagation when the critical tube diameter, d_c , associated with the FAE was greater than the minimum bag dimension. This observation was part of the motivation for undertaking a more extensive study of the influence of confinement on the transmission and propagation of detonation. This study, which is still in progress, makes use of the new FAE facility described above. Essentially two sets of related investigations have been undertaken. These include:

- i) determination of critical ethylene-air composition for transmission of detonation from tubes of diameters 0.3 m, 0.45 m and 0.89 m into a large bag, simulating an unconfined explosive cloud; and
- ii) a study of the transmission of detonation from a 0.89 m diameter rigid steel tube into 0.89 m diameter plastic bags of different wall thickness, providing different degrees of confinement.

Photographs illustrating the experimental configuration are shown in Figures 7 and 8. Typical sequences from the cinematographic records of the transmission process are included in Figures 9 and 10. A photograph of a typical smoked-foil record obtained in the tube is shown in Figure 11. These records, together with pressure and velocity records, are now being analyzed. The only complete data available at this time are the critical tube diameter results. These are compared with results from the Raufoss tests (12) in Figure 12. The solid curves are theoretical predictions based on the correlation proposed by Moen *et al.* (6) for initial pressures of 1 atm and 92.5 KPa (the mean atmospheric pressure on the DRES range). With the exception of the 0.45 m tube, there is good agreement with the Raufoss results.

A complete presentation and discussion of results will be available at a later date.

6. CONCLUDING REMARKS

The DRES FAE facility has been designed to be flexible enough to accommodate a variety of experimental investigations using a wide range of diagnostics. The flow system operates on a closed-loop cycle, continuously mixing the test gases with air, thereby providing a homogeneous mixture within the test volume in a short period of time. Real-time gas analysis, capable of simultaneous monitoring of a variety of hydrocarbon gases, is an integral part of the flow procedure. The flow and analysis system has been designed for both rapid turnover and versatility. In the experimental tests which have been performed to date, involving up to 35 m³ of explosive gas, the flow, mixing and analysis time is typically about one hour. After that time the ethylene concentration throughout the test volume is within $\pm 0.05\%$ of the desired concentration.

The current DRES large-scale FAE program is focused on the critical conditions for initiation and transmission of detonations in ethylene-air mixtures, and also the influence of confinement on the propagation of detonations. A series of tests has already been conducted and more are planned. In fact, it is expected that this test program will continue throughout the coming year, with the possibility of using different fuels to provide further experimental input to theoretical models and correlations. The field test program is being supported by laboratory-scale experiments using Schlieren photography for more detailed observations of the phenomena involved and also by theoretical and numerical calculations.

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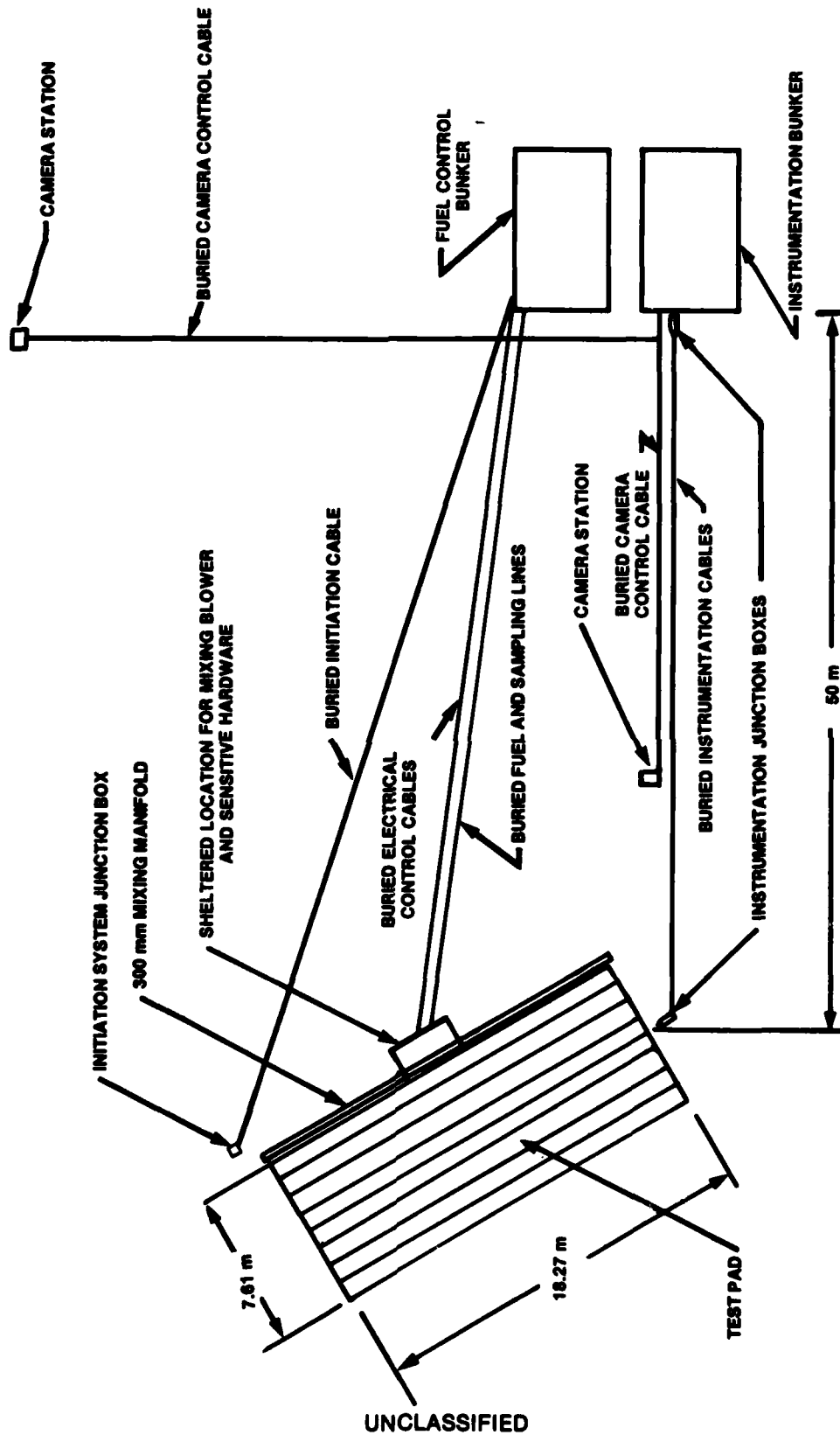


FIGURE 1
PLAN VIEW OF THE DRES FAE FACILITY

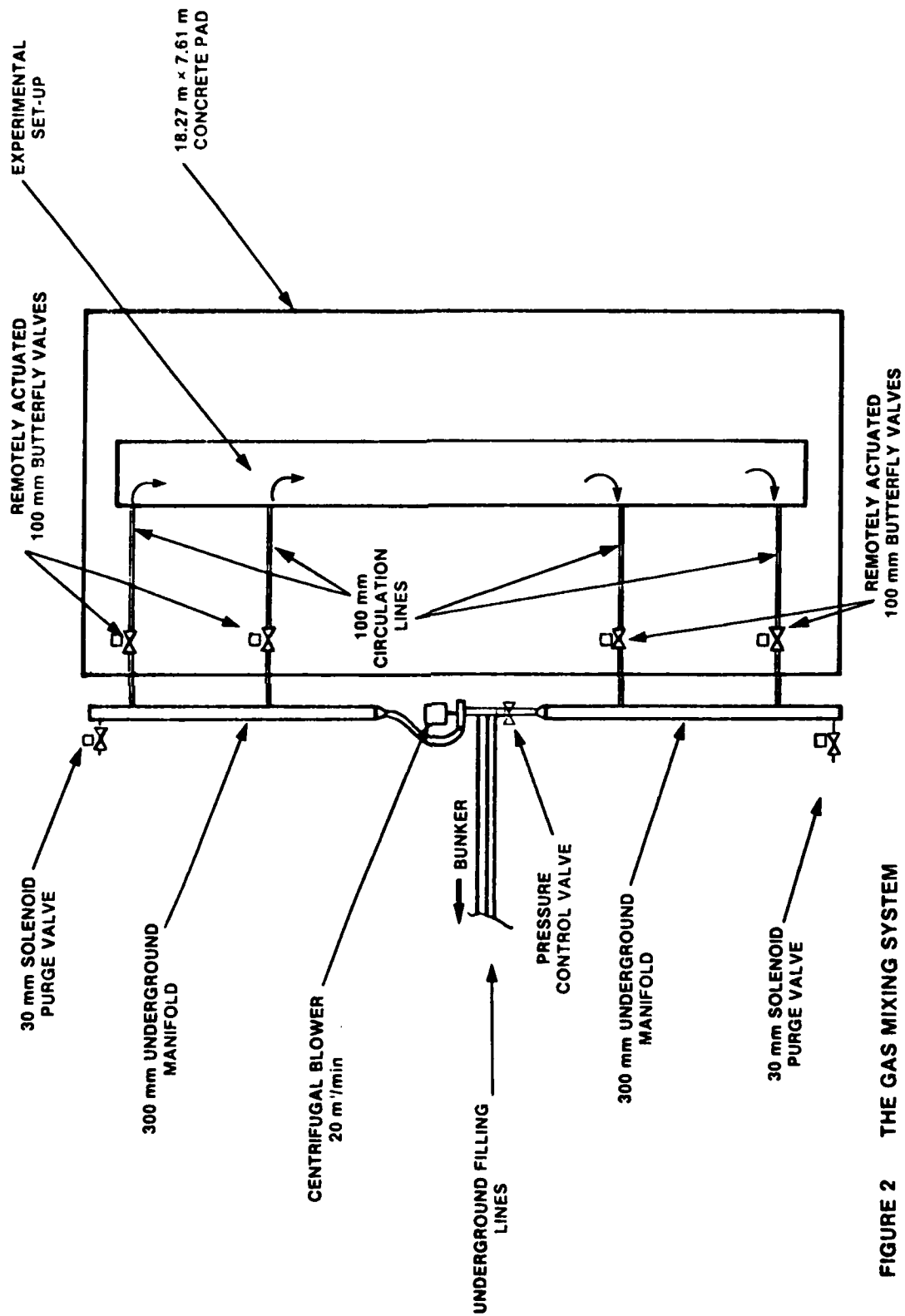


FIGURE 2 THE GAS MIXING SYSTEM

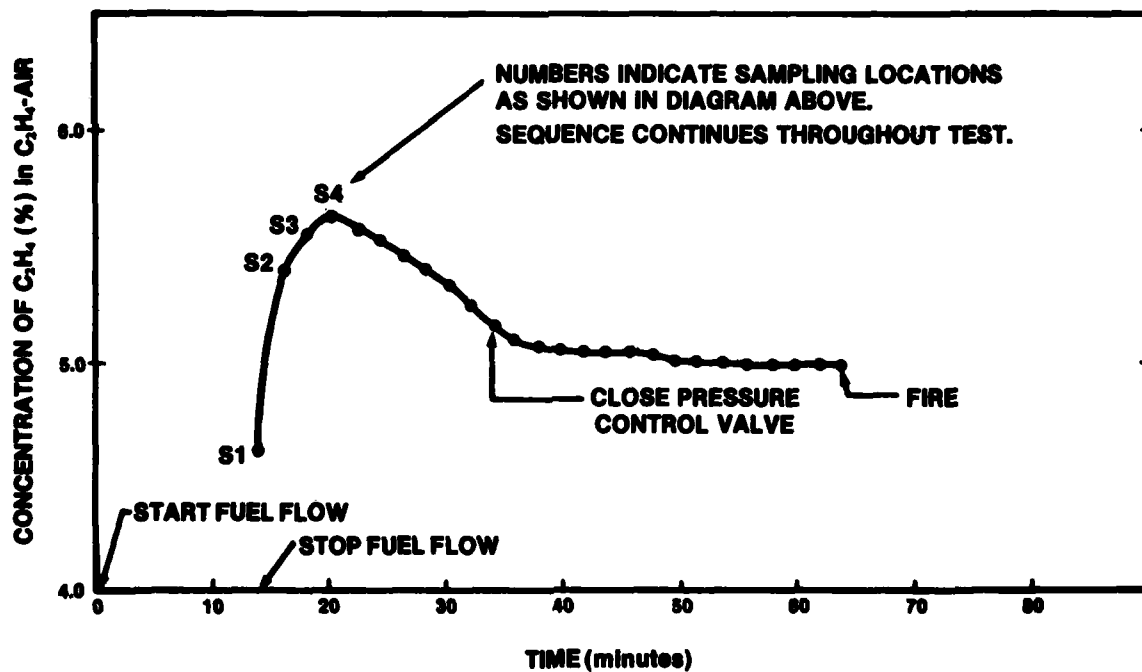
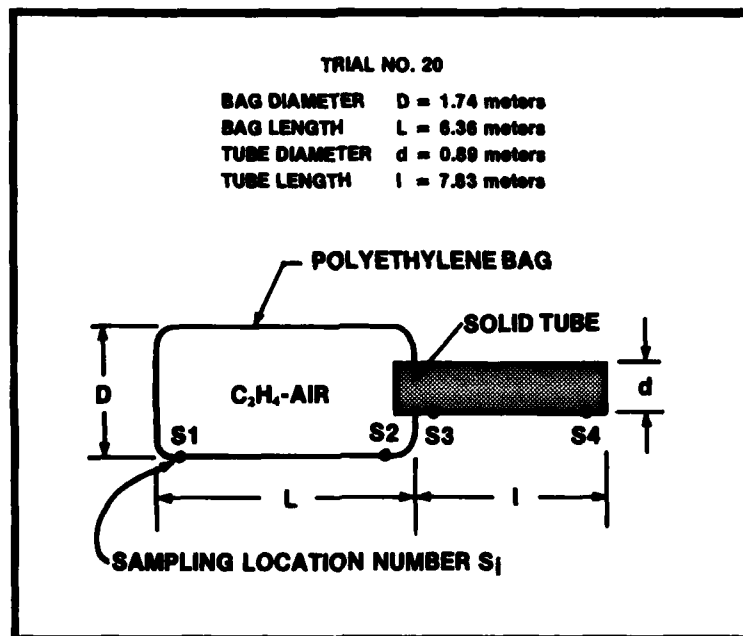
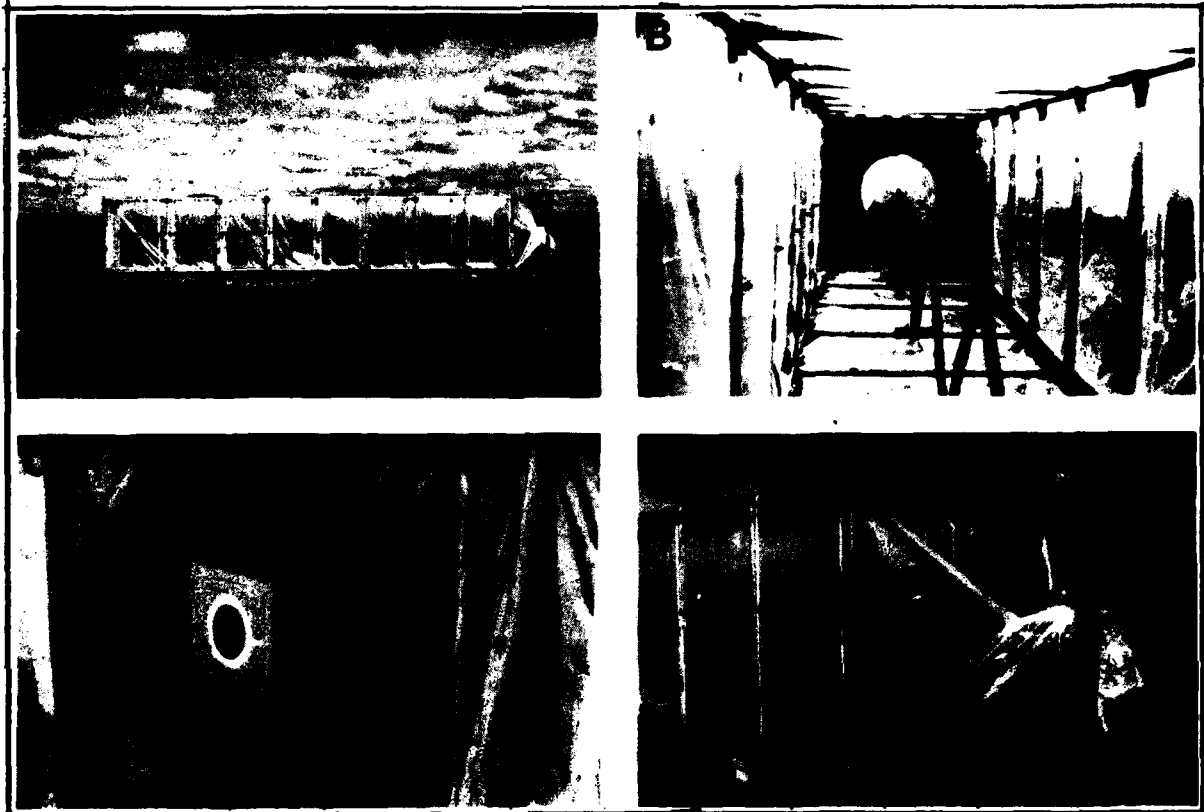


FIGURE 3
FUEL CONCENTRATION (% C_2H_4 IN C_2H_4 -AIR) VERSUS
TIME (MINUTES) FOR A TYPICAL EXPERIMENT.

**FIGURE 4****GAS BAG CONFIGURATION**

- a) EXTERIOR OF BAG READY FOR TESTING.**
- b) INTERIOR OF BAG SHOWING IONIZATION PROBE STING, PRESSURE TRANSDUCERS AND HOLE CUT IN IGNITION END.**
- c) IGNITION END OF BAG SHOWING INSTALLED INITIATOR DISC.**
- d) FAR END OF GAS BAG.**

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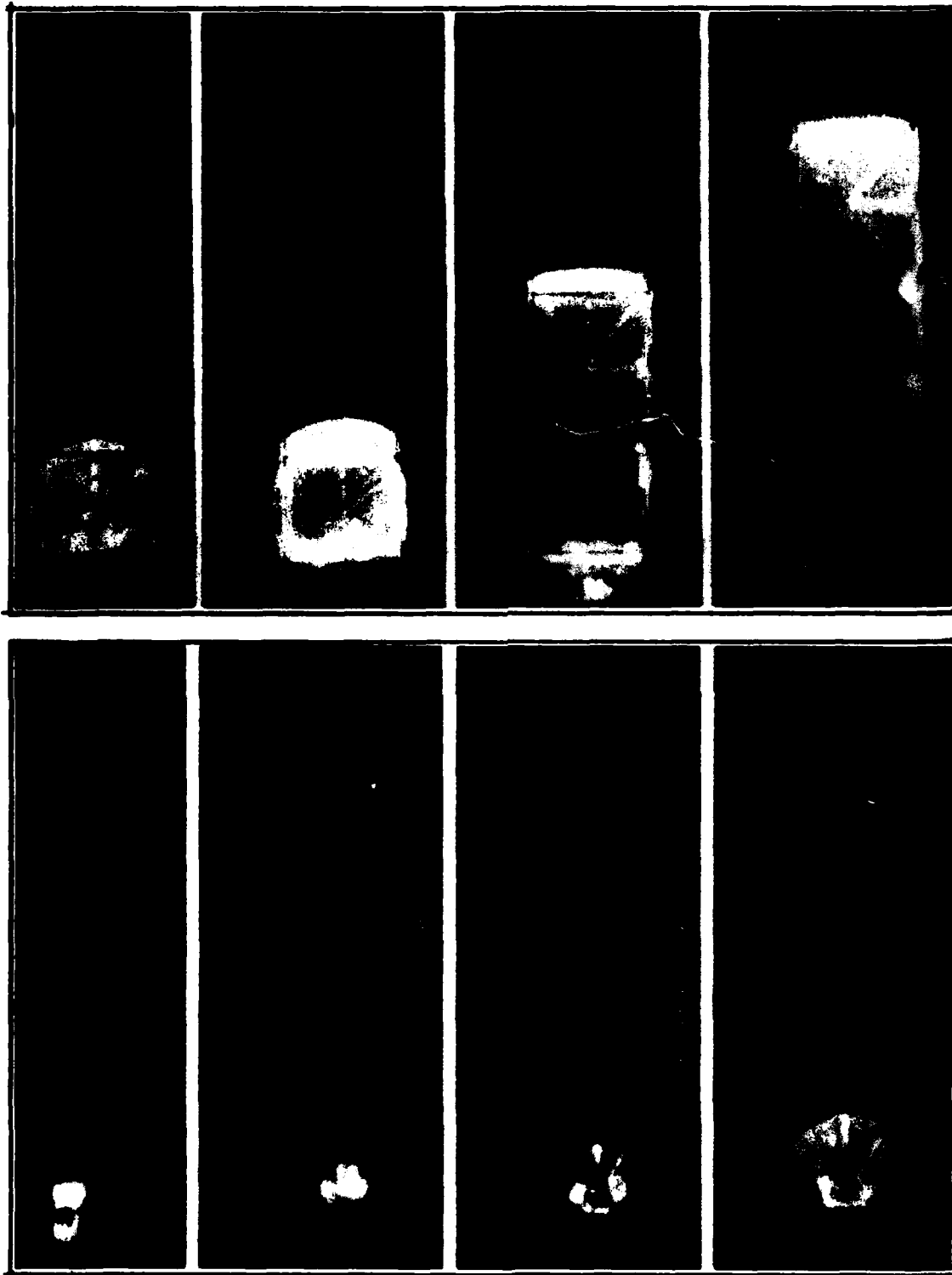


FIGURE 5

SELECTED FRAMES FROM A CINEMATOGRAPHIC RECORD — SUCCESSFUL INITIATION OF 8.4% C₂H₄ IN C₂H₂-AIR WITH INITIATOR DISC OF 102 mm DIAMETER (18 × 10⁻³ kg).

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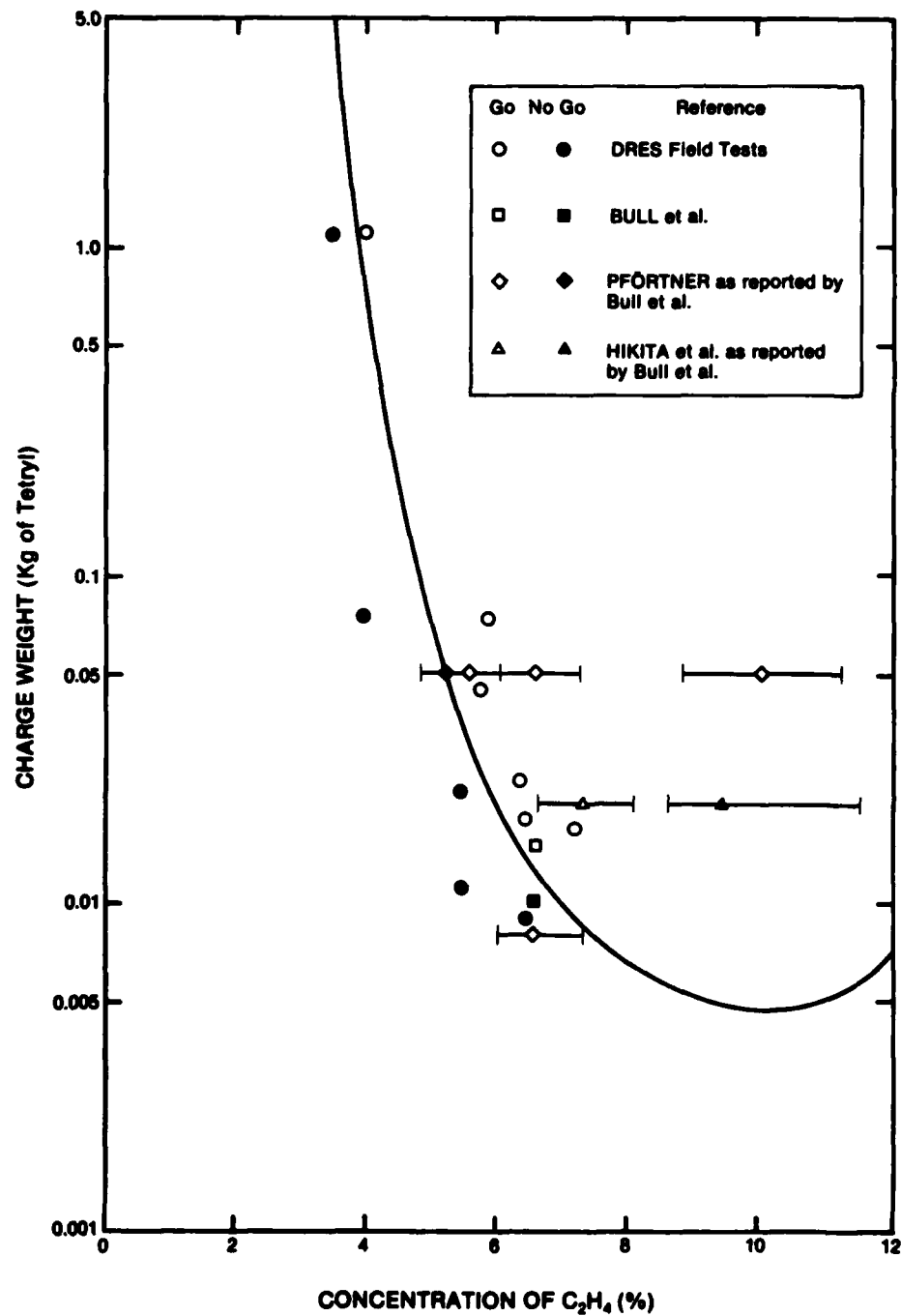


FIGURE 6
SOLID EXPLOSIVE INITIATOR CHARGE WEIGHT (KG OF TETRYL) VERSUS
% C_2H_4 IN C_2H_4 -AIR MIXTURES. BULL ET AL. - REF. 8, 9; HIKITA - REF.10.



FIGURE 7
PHOTOGRAPH SHOWING EXPERIMENTAL CONFIGURATION FOR CRITICAL
TUBE TEST. A SOLID TUBE OF 0.45 m DIAMETER AND PLASTIC BAG OF
1.75 m DIAMETER WERE USED IN THIS PARTICULAR TEST.

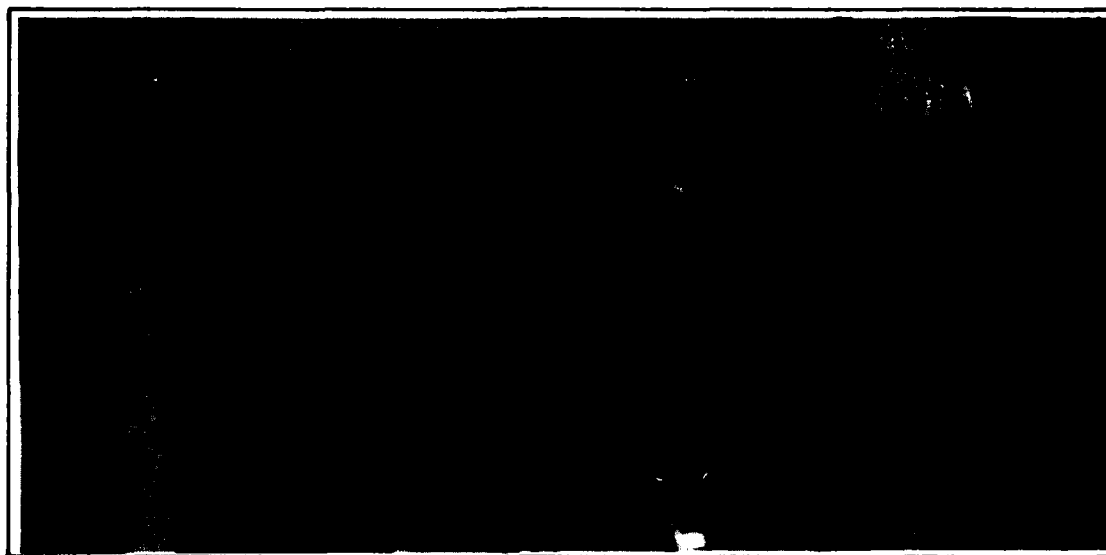
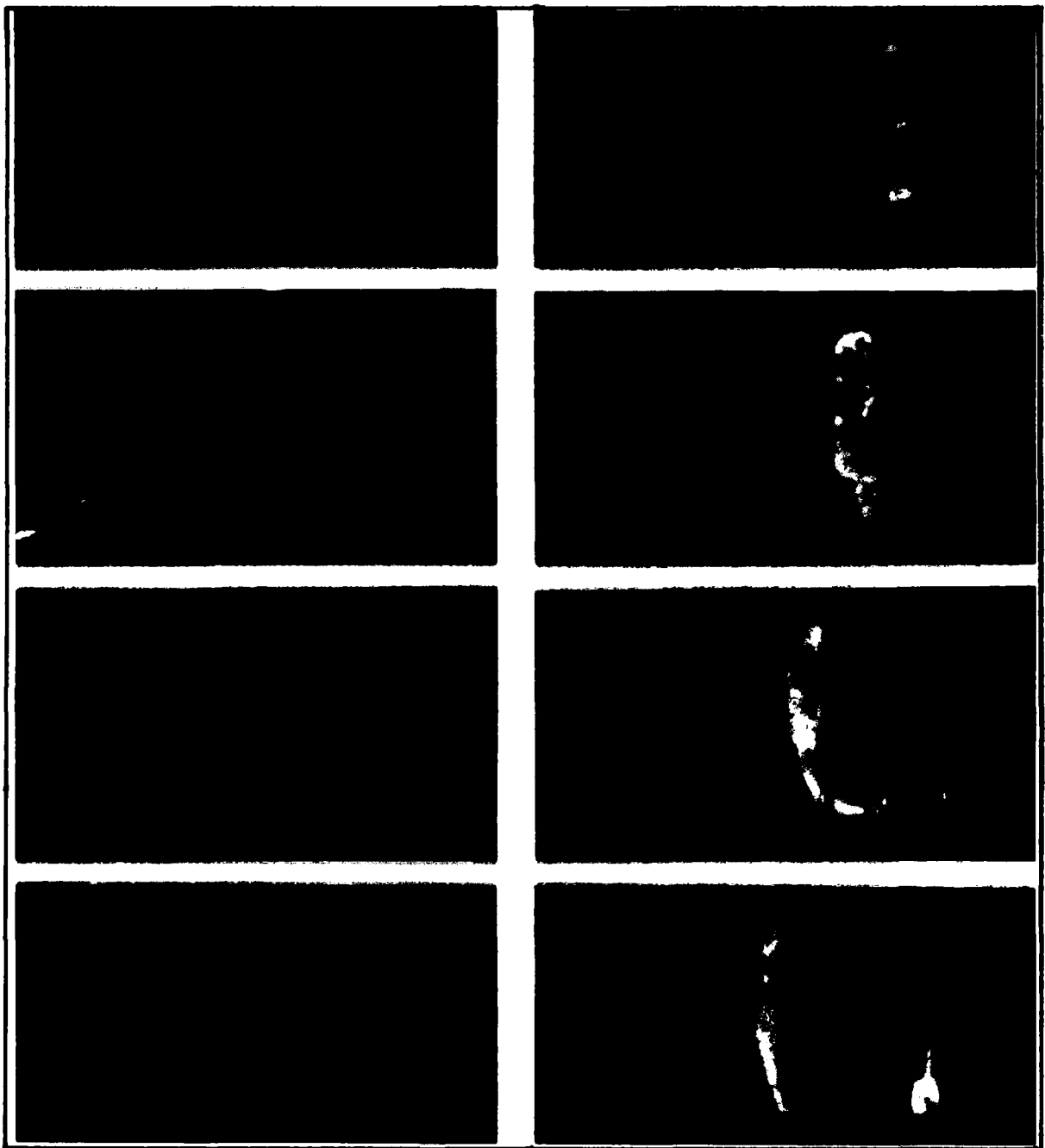


FIGURE 8

**PHOTOGRAPH SHOWING EXPERIMENTAL CONFIGURATION FOR A
CONFINEMENT TEST. A SOLID TUBE OF 0.89m DIAMETER AND A YIELDING
PLASTIC TUBE OF THE SAME DIAMETER WERE USED.**

**FIGURE 9**

**SELECTED FRAMES FROM A CINEMATOGRAPHIC RECORD SHOWING SUCCESSFUL
TRANSMISSION OF DETONATION FROM A CONFINED TUBE OF 0.89 m DIAMETER
TO A LARGE GAS BAG SIMULATING AN UNCONFINED ENVIRONMENT
(0.2 msec BETWEEN FRAMES).**

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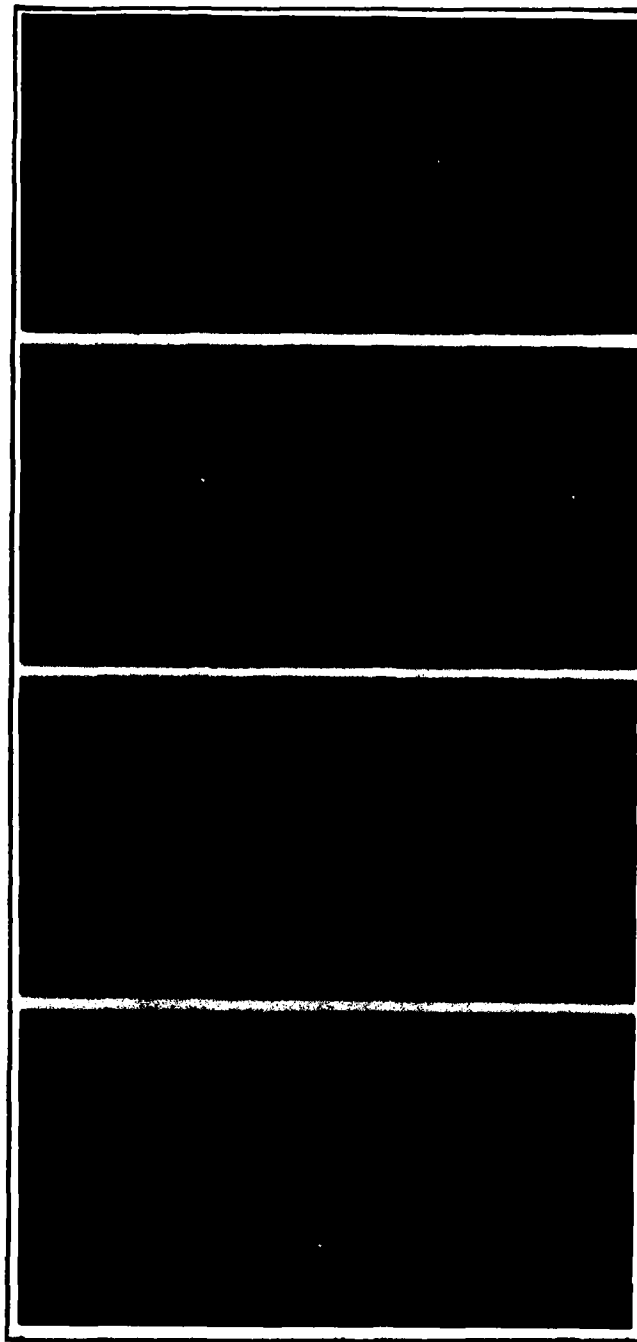


FIGURE 10
SELECTED FRAMES FROM A CINEMATOGRAPHIC RECORD SHOWING
TRANSMISSION OF DETONATION FROM A SOLID TUBE OF 0.89 m DIAMETER
TO A YIELDING TUBE (10 mil Plastic Bag) OF IDENTICAL DIAMETER
(0.6 msec BETWEEN FRAMES).

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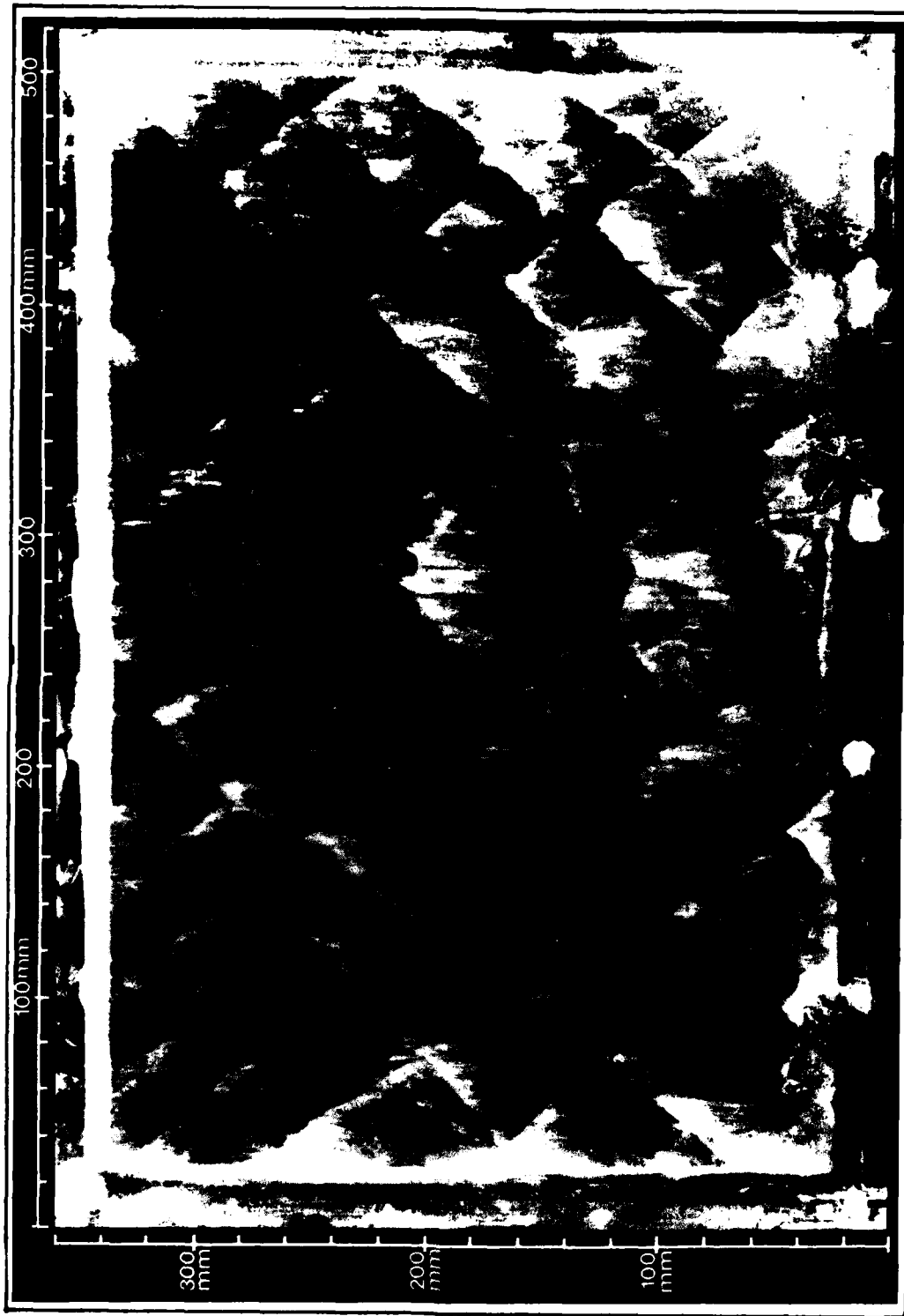


FIGURE 11
PHOTOGRAPH OF TYPICAL SMOKE-TRACK RECORD OBTAINED INSIDE A TUBE
OF 0.89 m DIAMETER. THE GAS MIXTURE WAS 4.6% C_2H_4 IN C_2H_4 -AIR.

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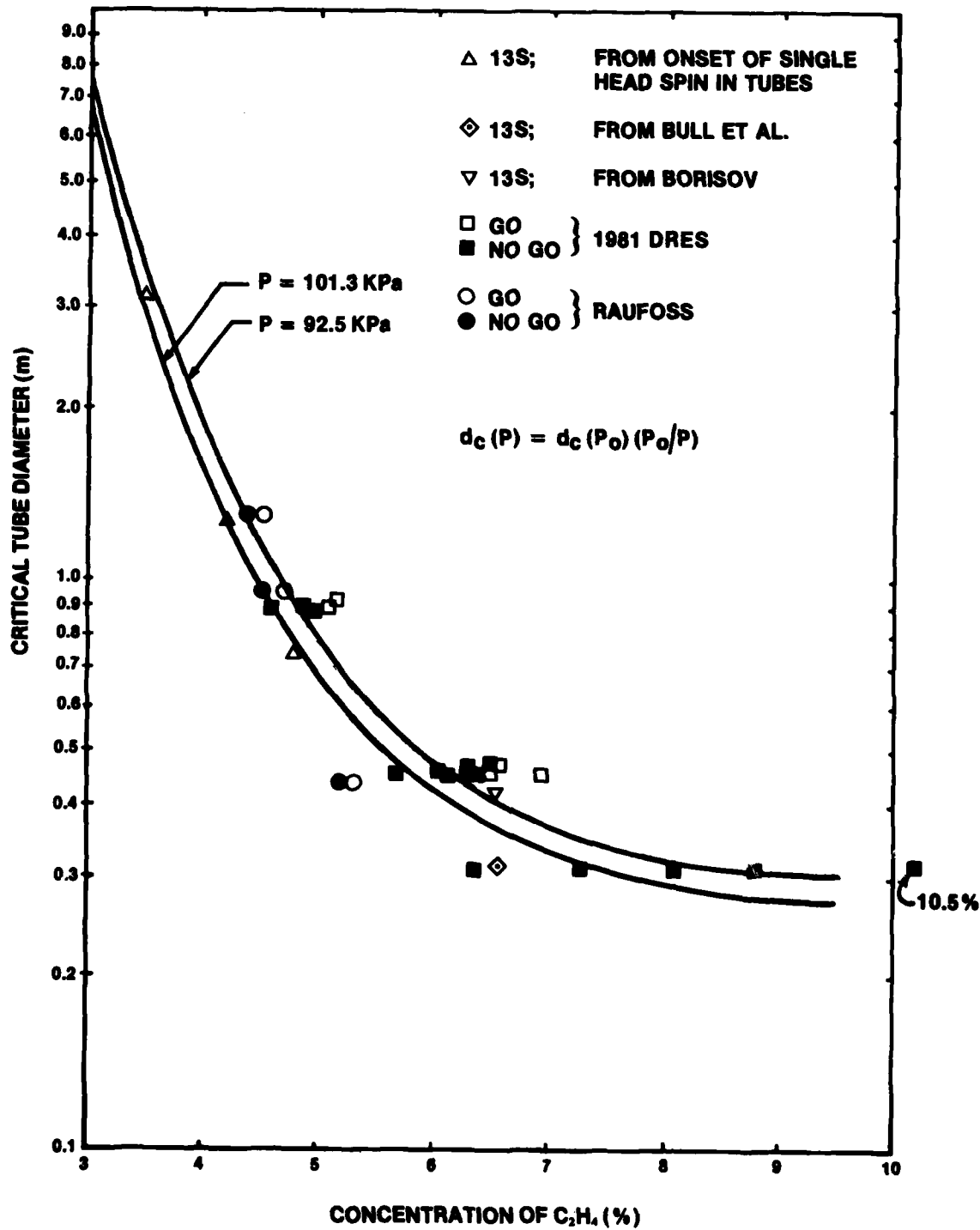


FIGURE 12
 CRITICAL TUBE DIAMETER (METERS) VERSUS ETHYLENE CONCENTRATION
 (% C_2H_4 IN C_2H_4 -AIR). BULL ET AL. - REF. 13; BORISOV - REF. 14;
 RAUFOSS TESTS - REF. 12; ONSET OF SINGLE-HEAD SPIN - REF. 6.

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KEY WORDS

fuel-air, vapour cloud, explosion, detonation, large-scale testing, ethylene-air, transmission of detonation, critical tube, initiation, initiation energy, transverse wave, detonation structure, influence of confinement

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