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DEFENCE RESEARCH ESTABLISHMENT SUFFIELD
RALSTON, ALBERTA

SUFFIELD SPECIAL PUBLICATION NO. 116

SOP NO. 415

FIRING AND SAFETY MANUAL FOR THE 1.8-METRE BLAST TUBE

by

D.V. Ritzel,
A. Doucet
and
M.G. Rude

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SUMMARY

The DRES Blast-Tube facility has been established to allow intermediate-scale blast experiments for the investigation of blast-wave flows and the response of structures and materials to blast loading from explosions in air. The Blast Tube is essentially a 50-m length of steel pipe of 1.8-m diameter with one end which tapers down to a 0.45-m closed end cap. A cloud of fuel-air explosive is dispersed within the tube at the closed end and detonated to create a blast wave which travels down the tube to the test section where required measurements are obtained.

To allow safe and effective operation of the Blast Tube, firing and safety procedures have to be established. This report describes the firing procedures and safety regulations to be used in the operation of the Blast Tube, including detailed descriptions of the operations required for dispersing and detonating the fuel-air cloud. Also described is the operation of special instrumentation for measurements of density-time records of the blast-wave flow which makes use of a radioactive beta source.

TABLE OF CONTENTS

Page

LIST OF FIGURES

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD
RALSTON, ALBERTA

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1.0 INTRODUCTION

A blast tube is a facility for creating controlled air blast waves which are used to investigate the physics of shock waves in air due to explosions, the nature of blast interaction with and loading of structures, and the response of materials, equipment and structures to blast. The purpose of such a facility is to simulate, in a controlled laboratory environment, the transient air shock-wave conditions (pressure, density, flow velocity, temperature, etc.) produced by explosions in air so that detailed measurements and observations assessing blast vulnerabilities can be made.

In its simplest form, a blast tube is a length of pipe with one closed end. A volume of gas is explosively released within the tube at the closed end; the violent expansion of gases drives a shock wave into the ambient gas ahead of it and down the pipe to the test section where blast experiments are performed. The section containing the 'driving' gases is called the driver section or driver. The explosive release of gases can be achieved by different methods, but primarily drivers are of two types: compressed-gas or combustion. In the first type, the shock wave is created by the very fast release of compressed gas from a high-pressure reservoir by breaking a diaphragm or opening a fast-acting valve. In the second approach an explosive is detonated in the driver creating a suddenly expanding volume of gaseous combustion products. The former DRES blast tube facility at the Building 15 complex used a 16-inch naval gun loaded with a solid explosive charge to produce a shock wave in the 1.8-m diameter test section. ["Firing and Safety Manual for Blast Simulation Laboratory and Shock Tube Laboratory", DRES SM 11/68]. In the late 70s that facility was dismantled.

Recent requirements for blast-effects studies called for the re-establishment of a blast tube at DRES. The new tube uses a dispersed gaseous explosive in the driver and includes other recent design developments. The development and construction of the facility is being supported by the research program of Shock and Blast Group (SBG/DRES), the Directorate and Maritime Engineering Support (DMES), and the Directorate of Maritime Engineering Maintenance (DMEM). Use of the facility will include both research into the phenomenology of blast flows, and test and evaluation of military structures vulnerable to blast loading.

2.0 THE DRES 1.8-M DIAMETER FUEL-AIR DRIVEN BLAST TUBE

The DRES Blast Tube is located approximately 400 m north of the Range and Accuracy (R&A) Site in the south-west corner of the DRES Experimental Proving Ground as shown on the area map in Figure 1. The site layout is shown in plan view in Figure 2. The configuration of the tube itself is shown as an elevation view in Figure 3. The main features of the tube are the driver section, the test station and the end-wave eliminator, separated by spans of straight 1.8-m diameter pipe.

The blast wave generated in the driver section propagates down the tube to the test station and then exits through the end-wave eliminator (EWE). The EWE is required to control the venting of the blast wave so that the blast flow at the test section is not adversely affected by shock or rarefaction waves reflected from the venting end. The lengths of straight pipe on either side of the test section are required to allow the blast flow at the test section to be properly developed into a smoothly decaying shock wave flow, free of perturbations from the driver or venting end.

This manual describes the procedures for flowing and detonating the explosive gases and also includes operating procedures for a special instrument for measurements of density-time records of the blast-wave flow. The blast densitometer operates on the principle of beta-attenuation and incorporates a radioactive beta-source element which must be used with care. Time-resolved measurements of density are critical for proper flow diagnostics and are particularly important for tests of drag-sensitive targets. A sketch of the densitometer mounted on the blast tube wall is shown in Figure 4. When the blast wave passes between the source and detector, the increased air density in the blast wave causes an increased absorption of the beta energy. The increased absorption results in lower energy being detected by the scintillator-PMT assembly, and the signal from this detector is conditioned to produce a time-resolved analog record of the density variation.

General firing procedures and safety regulations for the facility are enumerated in Section 3. A detailed breakdown and explanation of the firing procedures are outlined in Section 4. The summarized Firing Check Sheet, abort procedures for gaseous fuel detonation, and detailed operating procedures for the blast densitometer are given in Annexes A, B and C, respectively.

3.0 GENERAL PROCEDURES AND REGULATIONS

The following procedures and regulations shall apply at all times to any operation being conducted using the 1.8-metre Blast Tube. All personnel connected in any way with the conduct of tests using the 1.8-m Blast Tube are to read and become completely familiar with the contents of this manual.

3.1 Personnel and Responsibility

The responsibility for safety and operation is assigned as follows:

a. Overall responsibility for the installation and safe operations of the blast tube facilities and associated equipment is assigned to the Director/Defence Technologies Division. Scheduling of tests and establishment out-of-bounds areas must be coordinated with Head of Field Operations Section (H/FOS). Authority for day to day operations for the Blast Tube is delegated to an MES Scientist through Head of Military Engineering Section (H/MES). This person, who shall be called Head of Blast Tube Operations (H/BTO), is also responsible for coordinating site usage with H/FOS.

b. It is the responsibility of the H/BTO to instruct, train and advise all trials personnel, including contractors, under his direction in relation to the tasks they are required to perform, and to ensure that each individual is capable of performing competently and safely all tasks to which he is assigned.

c. Each firing shall be supervised by a designate appointed by H/BTO. This person shall be called the Blast-Tube Trials Officer (BTTO) and shall be responsible for complete control of all firing operations. He shall have the authority to postpone or cancel any firings in the interests of safety. All other personnel present shall follow his instructions during firing procedures. The BTTO must have adequate training and experience with the use of the fuel-air explosives system. BTTO will operate from the Blast Tube Control Centre as shown in Figure 2 and must have communication with all personnel on the site.

d. The BTTO will also be fully familiar with safety aspects involved with the use of the radioactive sources used in the density-gauge, which is intended as standard instrumentation installed in the test section. Two personnel, trained and experienced with the densitometer, will be responsible for the operations involving the set-up of the densitometer including handling of the beta source and normal decontamination procedures as described in Annex C. The regulations of the Atomic Energy Control Board (AECB) will be followed, and the DRES Radiation Safety Officer (RSO) will have final local authority on matter related to the storage, shipping inspection, handling and emergency procedures involved with use of the source.

e. The Fuel-Flow Controller (FFC) is responsible for all operations specifically concerned with the flowing of the gases used in the driver-gas detonation. FFC will operate from the Blast Tube Control Centre shown in Figure 2.

f. The Timing and Firing Officer (TFO) is responsible for control of the electrically-activated firing sequence including the final countdown sequence and abort control. The TFO may also be responsible for set-up, activation and playback of recording for instrumentation. TFO will operate from the instrumentation bunker shown in Figure 2.

3.2 Procedures in the Event of an Accident

a. All safety procedures are to be observed by all personnel at all times as specified in this manual. The advice and recommendations of the DRES Safety Committee will be followed.

b. In the event of a fire or explosive accident around the Blast Tube site, the following general actions in order of priority shall be the responsibility of the BTTO:

(i) Any persons injured shall be given first aid treatment and at the same time the Base Medical Centre shall be notified as to the nature of the injury by radio call through FOS/ALPHA.

(ii) Whenever possible remedial action shall be taken to prevent further injury to personnel or damage to equipment and installations. The primary concern to be addressed is any threat of fire to gaseous fuel reservoirs.

(iii) The accident shall be reported immediately to H/BTO and H/FOS who will then be responsible for any other administrative notifications within DRES. RSO will be contacted of the incident has involved or threatens to involve a radiation safety hazard due to the presence of the PM-147 beta source used in the densitometers.

(iv) The condition of the Blast Tube after the accident shall remain unchanged until the accident can be investigated by the DRES Safety Committee.

4.0 BLAST TUBE FIRING PROCEDURES

At all times during blast trials, the BTTO shall have responsibility for personnel safety and the correct conduct of procedures at the site. BTTO must contact H/FOS 24 hours in advance of any trials to confirm site usage and to arrange for any necessary FOS support. Blast Tube Control Centre has been set up at the site and shall be the communication centre of all trials.

4.1 Basic Firing Operation

The basic firing operation can be summarized as follows. Predetermined volumes of oxygen (O_2), acetylene (C_2H_2) and a gaseous hydrocarbon fuel such as ethylene (C_2H_4) are charged into separate pressurized reservoirs as shown in schematics of the fuel-flow system in Figures 5 and 6. A meterological balloon of appropriate size (1.2 to 7 m diameter capacity) is fitted over a nozzle in the conical initiator section from a fill line protruding through the closed end cap. The breech nozzle with spark igniter is shown in Figure 7. The oxygen and acetylene reservoirs are discharged to fill the relatively small initiator balloon in the conical initiator section to provide a stoichiometric mixture of oxy-acetylene. Once the oxy-acetylene balloon is filled to its predetermined capacity by emptying of the pressurized reservoirs, the ethylene reservoir is vented through gas lines to the central dispersal line in the cylindrical driver section. The ethylene reservoir is emptied to form a cloud of ethylene-air mixture of predetermined length in the driver section. An electrical spark is used to initiate detonation in the oxy-acetylene mixture at the apex of the conical initiator section. An oxy-acetylene detonation wave proceeds down the conical section, vaporizing the thin meterological balloon, until it reaches the ethylene-air cloud. The oxy-acetylene detonation is sufficiently energetic to initiate detonation in the less sensitive ethylene-air cloud. This detonation wave propagates through the fuel-air cloud. Peak pressures and durations required in the test section are controlled by the lengths of ethylene-air 'slug' in the driver. For weak blasts (less than 30 kPa), an oxy-acetylene balloon detonation alone will be a sufficient blast source.

Following a shot, the tube interior must be purged of combustion products. This purge is accomplished by activating blowers located at the end of the conical driver section. As shown in Figures 8a and 8b, a remotely controlled breech mechanism opens six ports on the end plate. A set of six blowers of 12 m^3/min capacity will draw fumes out through the breech end of the Tube and clean ambient air will be drawn in through the EWE. These blowers use compressed air to create a ring of high-speed air flow around the perimeter of the exhaust port directed out from the tube which draws gases from within the tube by a venturi effect. While the blowers displace all the gas in the tube in about two minutes, they will be activated for four minutes.

4.2 Firing Procedure Check List

The remainder of this section is a detailed breakdown and explanation of the items on the Firing Procedure Check List which are to be followed during each Blast Tube trial. The abbreviated Firing Procedure Check List to be used during trials is given in Annex A.

NOTE: Although a permanent densitometer will be mounted within the test section as a part of the Blast Tube facility, trials may not include the use of a densitometer, in which case, steps related to densitometer on the checklist which are identified by an item number with a "D-" prefix may be ignored.

PRELIMINARY PREPARATIONS AND INSPECTIONS

D-1. **Densitometer personnel verify the functioning of the densitometer.**

System tests are run to verify functioning of the densitometer's instrumentation. These tests need only be performed at the beginning of each trial day and can be performed without the radiation source in place.

D-2. **A rope barrier with a "radiation hazard" sign is set across the access to the test section.**

All personnel other than the densitometer personnel must vacate the inside of the Blast Tube during installation and removal of the source sting.

D-3. **Densitometer personnel remove the source-sting assembly from locked storage and mount the shielded assembly in the Blast Tube.**

A locked cabinet designated with 'radiation hazard' signs will be used to store the source-sting assembly in its transportation container in the control centre at the site. At the start of daily operations the sting assemblies will be inspected for leakage and mounted in the Tube.

D-4. **Densitometer personnel install the source sting with the lead shield covering the sting head.**

It is important to keep the lead shield (see Annex C) on while mounting the source sting in order to contain the emitted radiation. The densitometer personnel will be equipped with a beta-sensitive detector and proper protective clothing during this operation.

D-5. **Densitometer personnel calibrate the densitometer.**

After temporarilly removing the lead shield, the densitometer is calibrated. A detailed calibration should be performed at least once each trial series and checked daily using a test beta absorber in the beam. The lead shield is replaced upon completion of calibrations.

D-6. **Rope barrier with "radiation hazard" sign is removed from access point to test section.**

Once the source sting has been mounted and the densitometer calibrated, the lead shield will have been replaced over the source. Access to the test section should be unrestricted and the rope barrier can be removed. However radiation warning plaques will remain posted at the access to the test section and the source-sting assembly will be clearly marked with a radiation-hazard sticker.

7. **BTTO inspects exposed gas lines, fittings, and cabling, and the exterior of the driver section for any indication of damage or poor condition.**

A walk-around the facility is required to inspect critical components and to ensure no potentially hazardous condition is developing from shot to shot.

8. **FFC opens the required gas bottles and verifies that they are sufficiently full for the trial.**

Each trial requires typically four gases which are: acetylene and oxygen for the initiator balloon, ethylene for the main driver explosive, and air for the venting blowers. Pressurized air will also be used to activate the ball valve for the dispersion of the ethylene. For low overpressure requirements in the driver-section, the initiator balloon alone would suffice and therefore no ethylene is required (see Figure 5).

9. **FFC evacuates all gas reservoirs.**

The vacuum pump is used to evacuate all gases from the gas reservoirs which are shown as tanks in Figure 4. This is done once at the beginning of each trial day. This ensures that no air mixes with either the acetylene, ethylene or oxygen.

10. **BTTO confirms that the "spark-ignitor" is in place and functional by conducting a "SPARK TEST".**

BTTO must verify that a spark is created when three thousand volts (3000 V) is applied across the two probes in the spark-ignitor. This is verified by activating the spark-ignitor without a mounted balloon. The voltage is applied by the use of a Reynold's Bridge system (remotely controlled by TFO from the instrumentation trailer).

11. **BTTO confirms that the hot wire is functional by conducting a "HOT WIRE TEST".**

BTTO must verify that the hot wire becomes red hot when fifteen volts (15V) is applied across the ends of the wire (remotely controlled from the Blast Tube Control Centre).

12. **Initiation balloon is mounted** as shown in Figure 7.

13. **Hot wire is properly mounted around the neck of the initiation balloon** as shown in Figure 7.

The hot wire should be mounted in such a manner that in the case of an abort the hot wire system would either burn through the balloon dislodging it from the oxy-acetylene filling assembly or detonate the oxy-acetylene mixture (see Annex B).

14. **BTTO must confirm by close inspection that the balloon and hot wire are properly mounted.**

FINAL CHECKS

15. **BTTO checks with the experimentor to ensure that all experiment preparations are complete.**

D-16. **Densitometer personnel remove lead shield from source sting before each shot.**

As the final operation in the test section after set-up of any targets and instrumentation before closure of the test section, densitometer personnel remove the lead source shield and thereby activate the densitometer for the shot.

D-17. **BTTO checks closure and locking of test section.**

18. **BTTO ensures that all diagnostic and flow equipment is ready and operating.**

BTTO checks with the following personnel to make sure all relevent equipment is ready:

(i) Timing and Firing Officer (TFO),
(ii) Fuel-Flow Controller (FFC),
(iii) Densitometer Personnef,
(iv) Camera Operator (if any).

19. **A barricade is set-up closing the access road to the immediate test area.**

A barricade indicating "EXPLOSIVES TRIAL IN PROGRESS" is placed closing the access road to the immediate test site as shown in Figure 2. Inform ALPHA barricade in place and area is closed.

20. **Activate flashing amber caution lights on roadway.**

Amber caution lights, placed 200 m to the north and south of the site along Trafford trial, are activated to warn oncoming traffic of blast trials in progress. Although there is no direct physical hazard, the startle effect of the venting blast could be of concern.

21. **BTTO confirms positioning of the barricade by visual inspection and/or by radio.**

22. **All personnel report to proper firing stations and observation points except BTTO and FFC.**

Personnel on site should be stationed as follows:

(i) Instrumentation Trailer

- TFO
- One Observer (max)

(ii) Blast Tube Control Centre

- Densitometer Personnel
- Two Observers (max)

(iii) Vehicles in Parking Area

- Other support personnel and observers.

All non-essential personnel will proceed to their observation posts. No observers are allowed in any area where the blast overpressure has been determined to exceed 0.14 kPa (0.02 psi) peak amplitude.

TRIAL PROCEDURE

23. **FFC disconnects the vacuum pump and loads both the initiator gas reservoirs and the driving fuel dispersion tank.**

A predetermined amount of ethylene is loaded into the driving fuel dispersion tank along with a predetermined amount of oxygen and acetylene which are loaded into the initiator gas reservoirs as shown in Figure 5. The amount of each gas is calculated before the trial. These quantities are crucial in obtaining the required blast wave overpressure in the test-section. The quantity of the gas is calculated based on the volume of the reservoir tank and the pressure of the gas inside the tank.

24. **BTTO removes the "firing plug" from the test pad.**

BTTO removes the firing plug from the test pad module and gives it to the TFO in the instrumentation trailer.

25. **BTTO and FFC proceed to Blast Tube Control Centre.**

26. **BTTO proceeds with final personnel check by radio call.**

BTTO checks by radio call that all trials personnel are at their proper firing stations and are ready to proceed. Trials personnel will also report for observers at their stations.

27. **BTTO proceeds with final visual inspection.**

BTTO ensures test area is clear by visual inspection.

28. **BTTO requests permission to commence firing sequence by a radio call to FOS/ALPHA.**

After approval from FOS/ALPHA BTTO informs TFO that the trial is ready to proceed. After confirmation of TFO readiness, BTTO ensures that the test area is clear by visual inspection before granting permission to commence firing sequence.

29. **BTTO gives FFC permission to begin flowing initiation gases.**

The initiation gases are comprised of a fuel-oxygen mixture (e.g., oxy-acetylene) and are mixed via the filling assembly mounted on the endplate of the Blast Tube and loaded into the initiation balloon located on the inside of the Blast Tube. Approximate filling time is two minutes.

30. **FFC notifies BTTO when initiation gases are loaded and advises when driving-fuel dispersion will be activated in the countdown.**

When the correct amount of oxy-acetylene mixture has been loaded, FFC announces when fuel dispersion will be activated. For smaller strength blast trials the oxy-acetylene initiation balloon will yield enough overpressure in which case this step and Step 34 will be eliminated.

31. **BTTO instructs TFO to commence firing sequence.**

After confirmation from TFO, BTTO notifies all trial personnel that the final firing sequence has begun.

FIRING SEQUENCE

32. **TFO inserts "firing plug" into the instrumentation trailer firing module.**

NOTE: Steps 33 to 35 should be synchronized according to TFO's countdown and will run continuously.

33. **TFO starts countdown at T minus 15 seconds while announcing "T minus 15 seconds".**

34. **FFC activates driving fuel dispersion at the prescribed time and announces "fuel dispersing".**

TFO activates the ball valve which releases the gaseous fuel into the driver-section of the Blast Tube via the dispersion sting. Maximum dispersion time should be approximately five seconds (for 2000 kPa reservoir pressure) for a full driver section cloud but will vary slightly depending on desired cloud size. The remaining time in the countdown is required for the dispersed gas to mix uniformly with the ambient air in the tube.

35. **FIRE at T equal zero**

TFO activates the "spark-ignitor" at the end of the countdown and records the actual time of the shot on the Firing Procedures Check List. If the ignitor fails to ignite the fuel-air mixture abort procedures as outlined in Annex B are followed.

POST TRIAL CHECKS

D-36. **BTTO confirms with Recording Operator/TFO that densitometer is still operational by presence of typical signal level on gauge output.**

If no densitometer signal or very weak signal is observed a hazardous situation may exist in the Tube in that the source may have been dislodged or damaged. Re-entry should proceed as usual except that the radiation hazard inspection will be particularly cautious and thorough.

37. **BTTO takes firing plug from TFO and returns it to the test pad module accompanied by densitometer personnel.**

NOTE: The chance of a dual fuel-air and radiation hazard occurring is considered to be very small, but if this situation were to arise the Fuel-Air Abort Procedure (Annex B) is first initiated and then the Radiation Emergency Procedures (Annex C).

38. **BTTO inspects the exterior of the driver-end of the Blast Tube for damage, fire, or leaking gas hazards and announces his assessment.**

If a combustion hazard exists, fire safety procedure will be invoked. Even if clear of fuel hazards, all personnel must remain at their safety stations until remaining hazards are cleared.

39. **BTTO activates the blowers to clear the Tube of fumes.**

By remote control the venting ports in the breech are opened and the blowers are activated to draw fumes out through the breech. The blowers will be run at least twice as long as required to displace all gas in the Tube based on the blower performance rating.

D-40. **BTTO gives densitometer personnel permission to proceed with densitometer inspection.**

If no fuel-air hazards are present after BTTO's inspection of the exterior of the driver-end, then the densitometer is inspected for radiation leakage.

D-41. **Densitometer personnel proceed with radiation hazard inspection.**

Personnel will be suitably equipped with monitors and clothed in coveralls, gloves, rubber boots and gauze masks. From outside the tube, personnel remove the source sting by unbolting the back place (Figure 4) and carefully removing the sting with back place so as to not expose human tissue to the radiation beam. The lead shield is secured over the source and the sting is swabbed for traces of leakage.

D-42. **Densitometer personnel declare result of densitometer inspection to BTTO. If no leakage is evident, proceed to step 43. If leakage is evident, the source sting assembly is bagged and labelled and contained as for leaking source material; Emergency Procedure described in Section 7 of Annex C are then followed.**

43. **If clear of all hazards, BTTO announces on the radio: "BLAST TUBE ALL CLEAR TO PERSONNEL".**

Once BTTO is satisfied of complete safety, the "All Clear" signal is given whereby test personnel may approach the test pad in order to inspect or dismantle the experiment, or set up the next trial.

ABORT PROCEDURES for gaseous explosive initiation are given in Annex B.

RADIATION EMERGENCY PROCEDURES are given in Annex C.

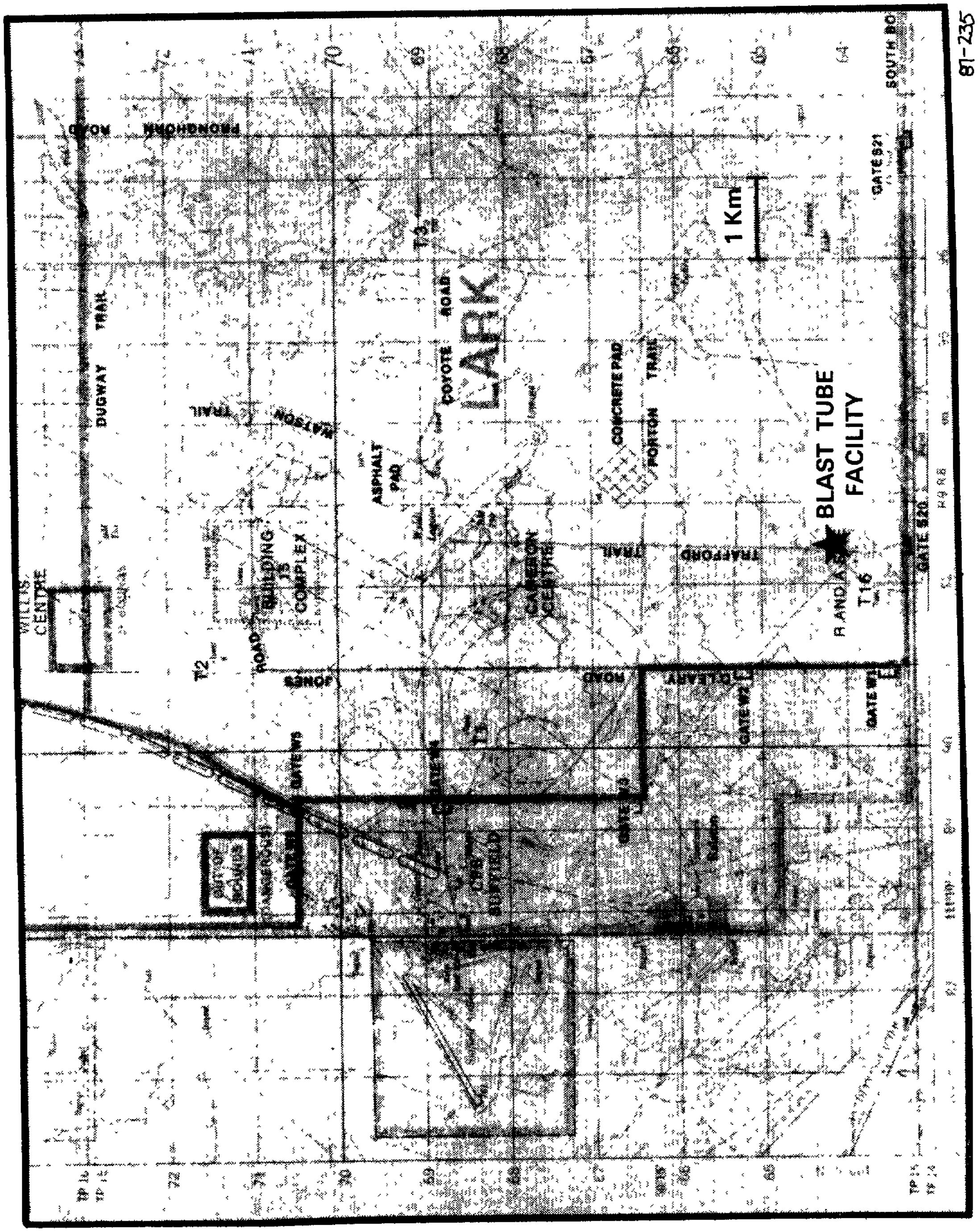

Figure 1

MAP OF THE SOUTH-WEST AREA OF THE DRES EXPERIMENTAL PROVING GROUND SHOWING THE BLAST TUBE SITE

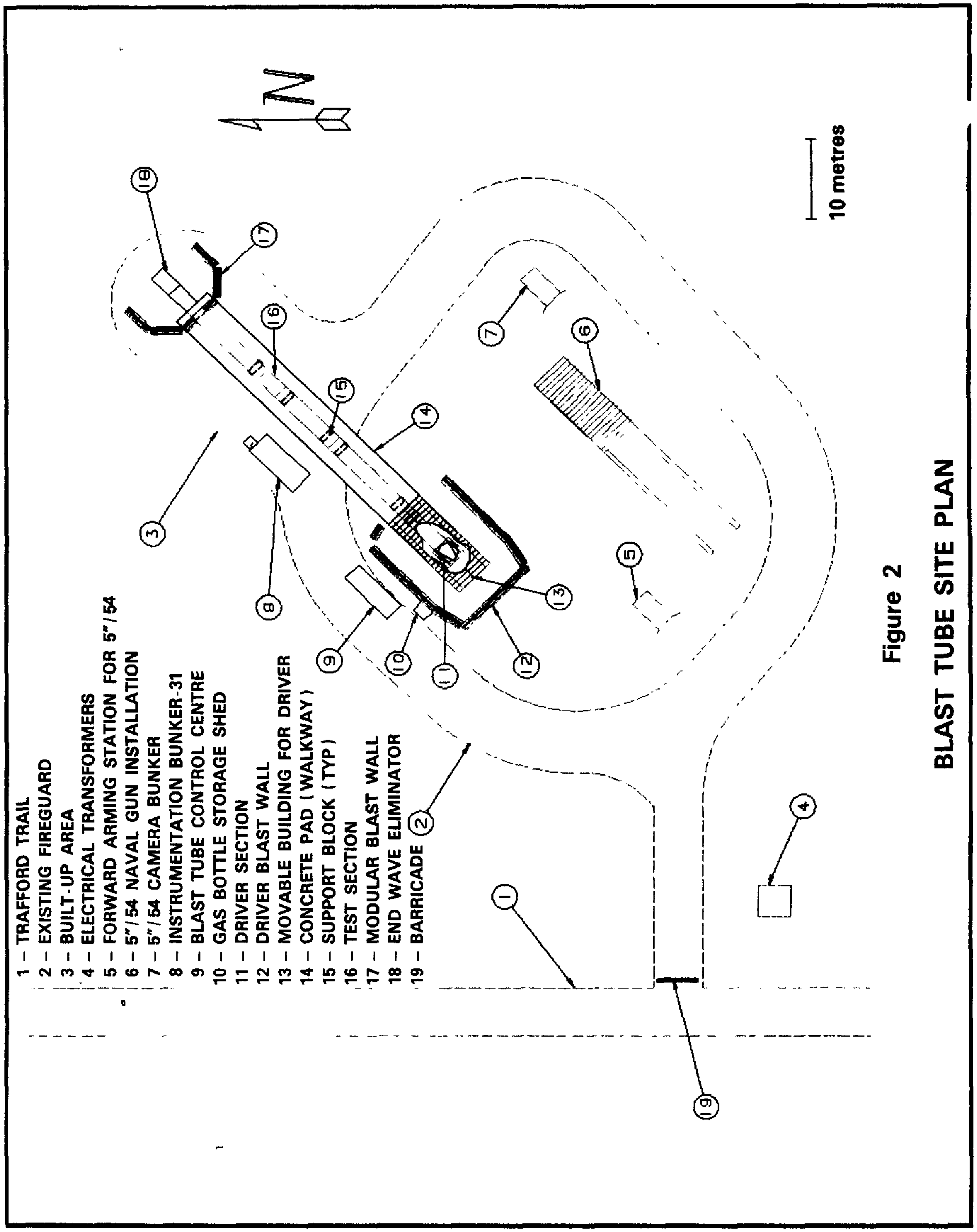

Figure 2
BLAST TUBE SITE PLAN

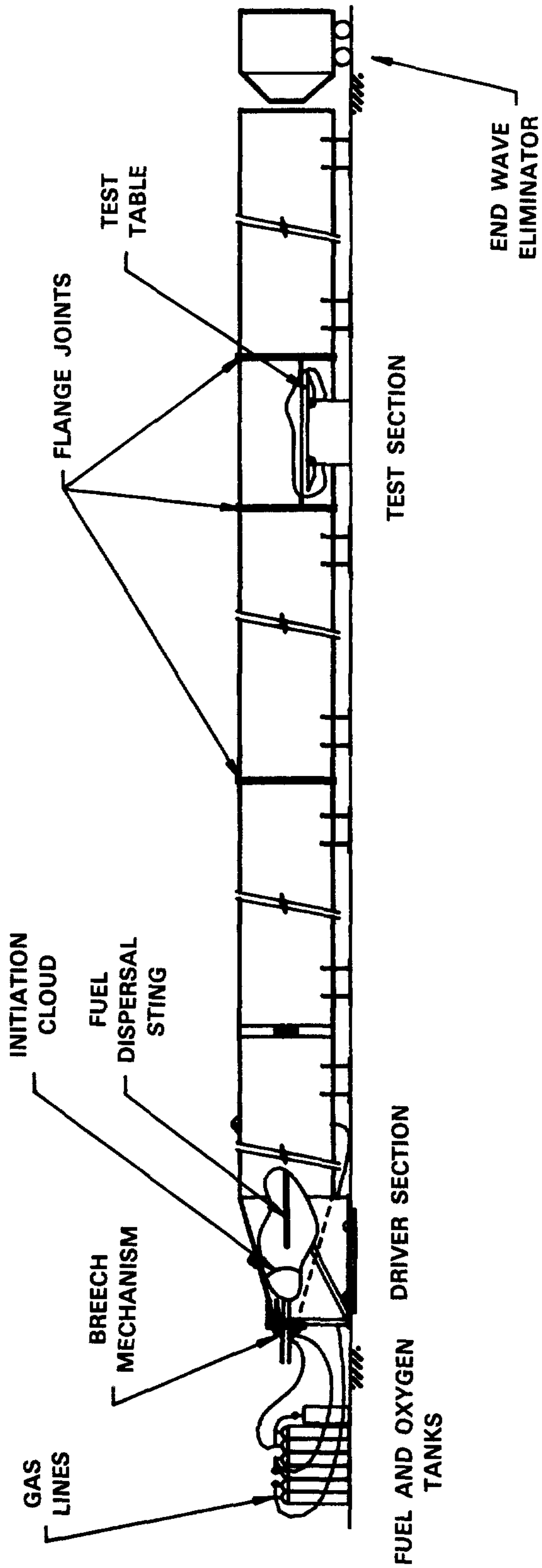

Figure 3

BLAST TUBE CONFIGURATION, ELEVATION VIEW

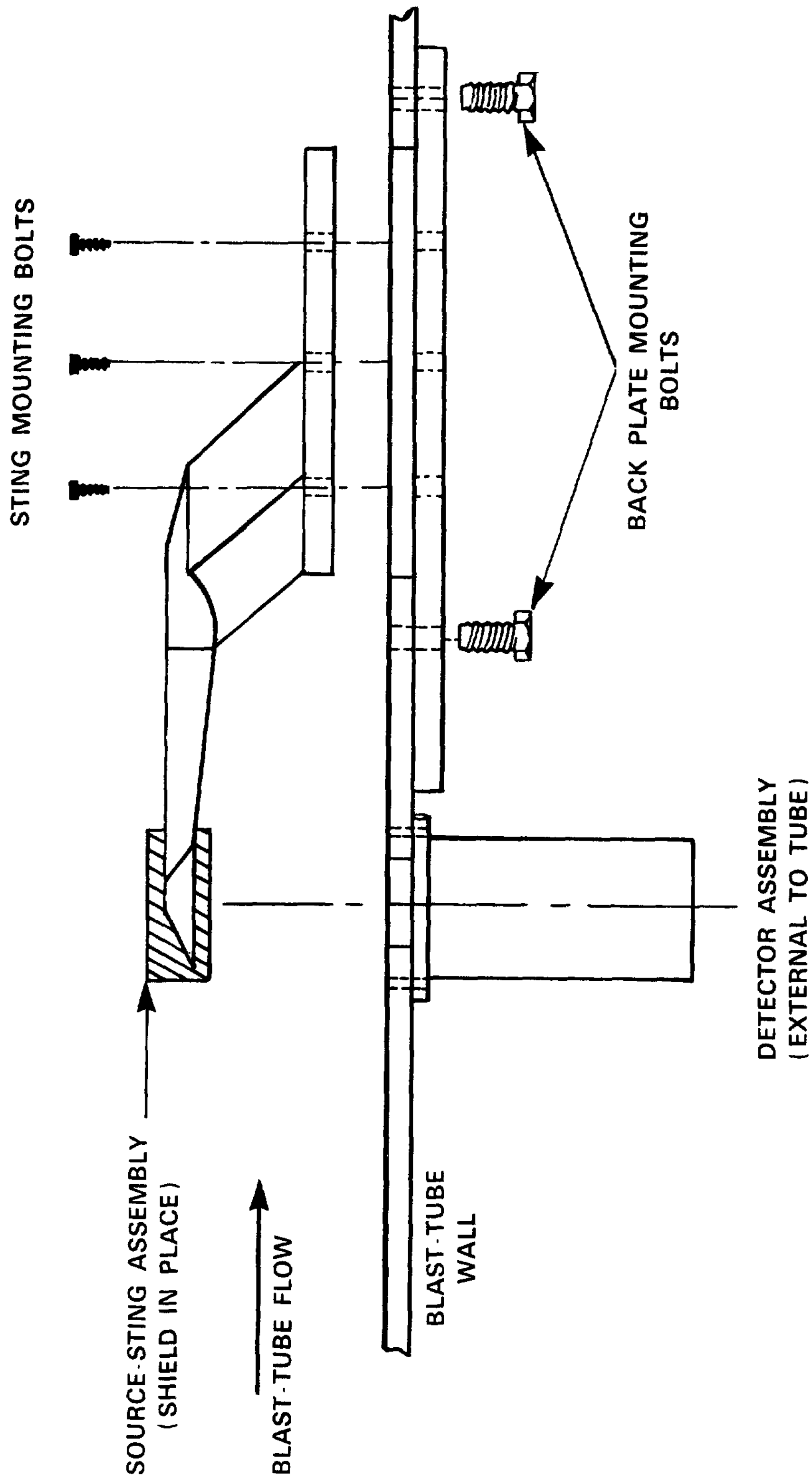

Figure 4

MOUNTING ARRANGEMENT OF A BLAST DENSITOMETER IN THE WALL OF THE BLAST TUBE

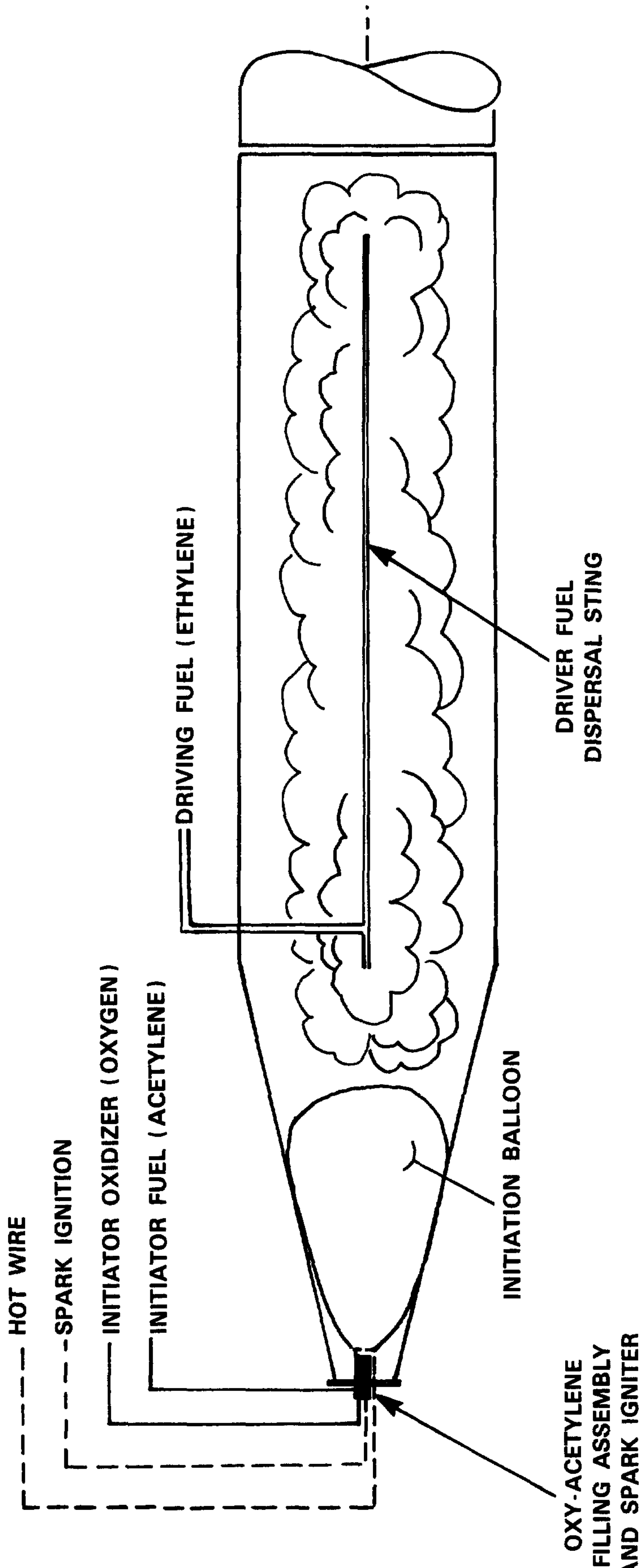

Figure 5

DRIVER SECTION SCHEMATIC

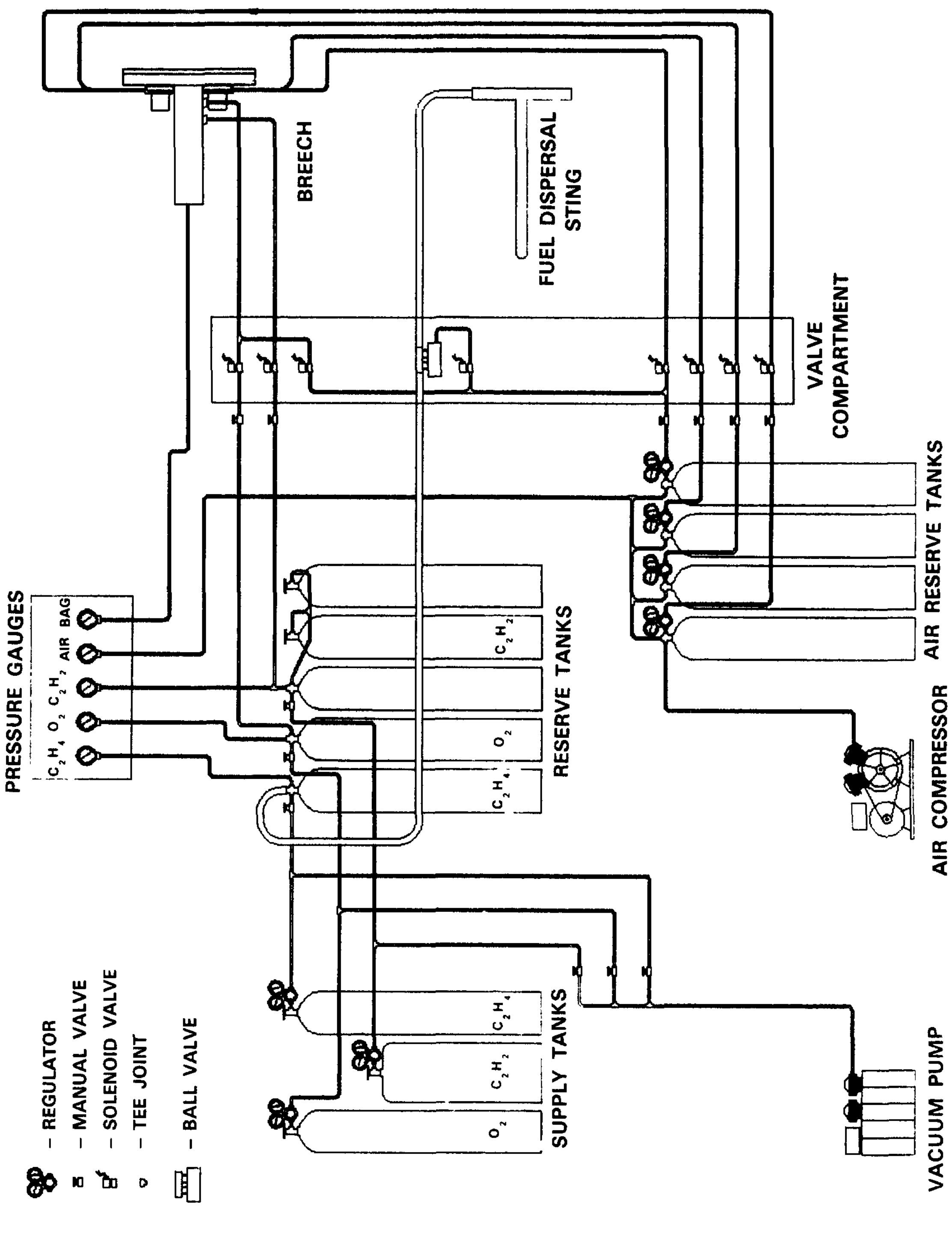

Figure 6
GAS-FLOW SYSTEM SCHEMATIC

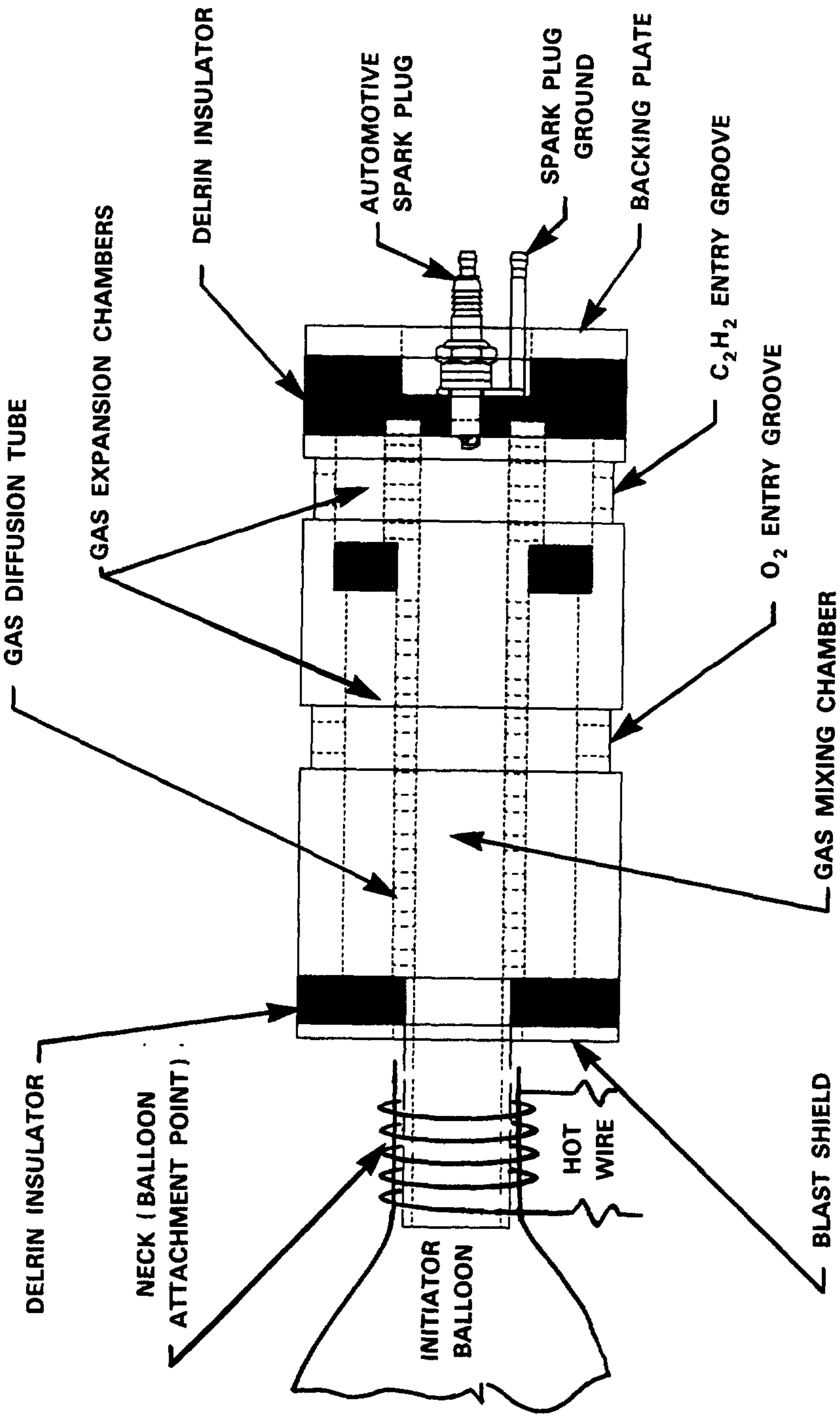

Figure 7

OXY-ACETYLENE NOZZLE AND IGNITION SYSTEM IN BREECH

UNCLASSIFIED

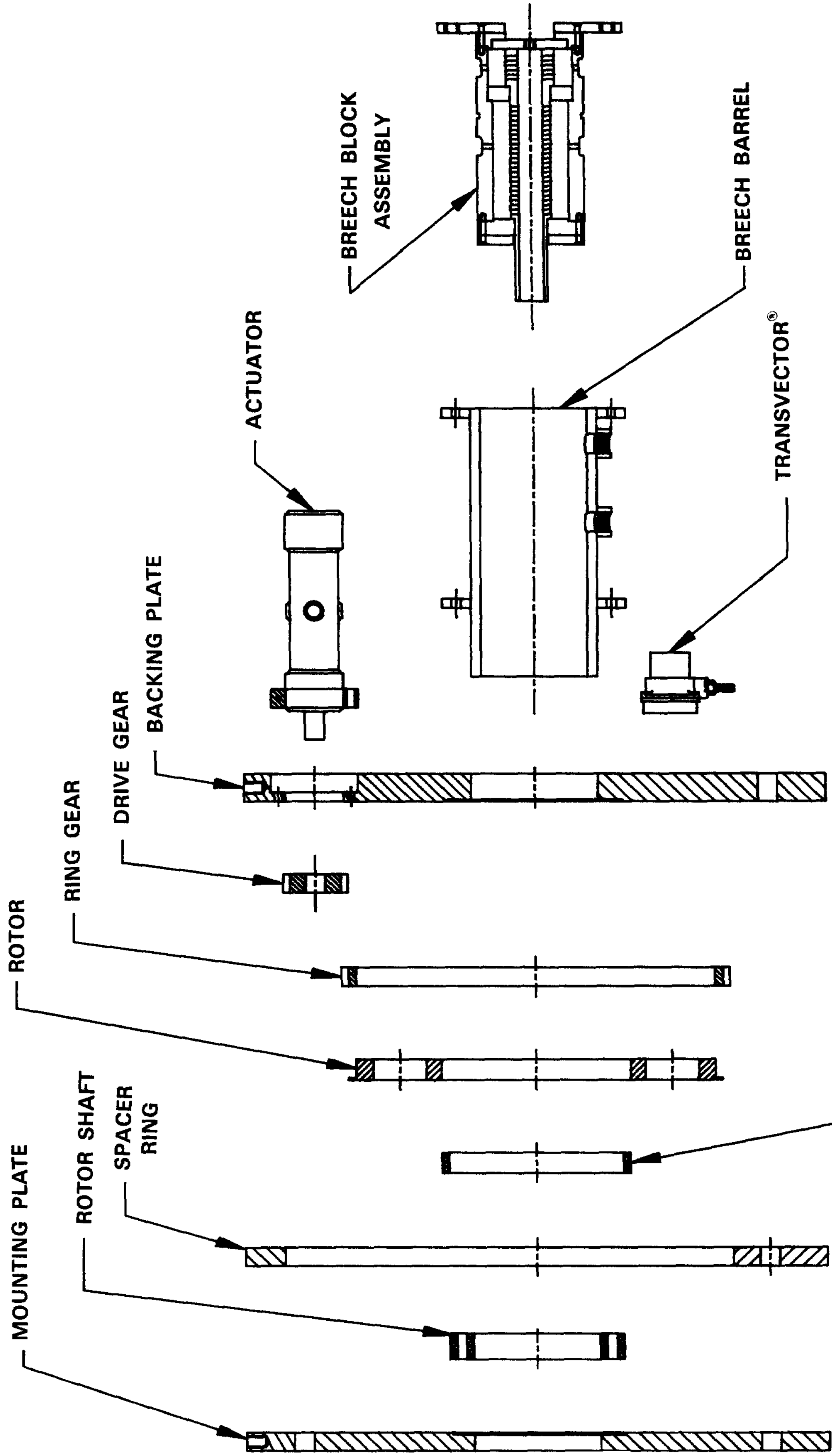

Figure 8a

PURGING SYSTEM, EXPLODED VIEW

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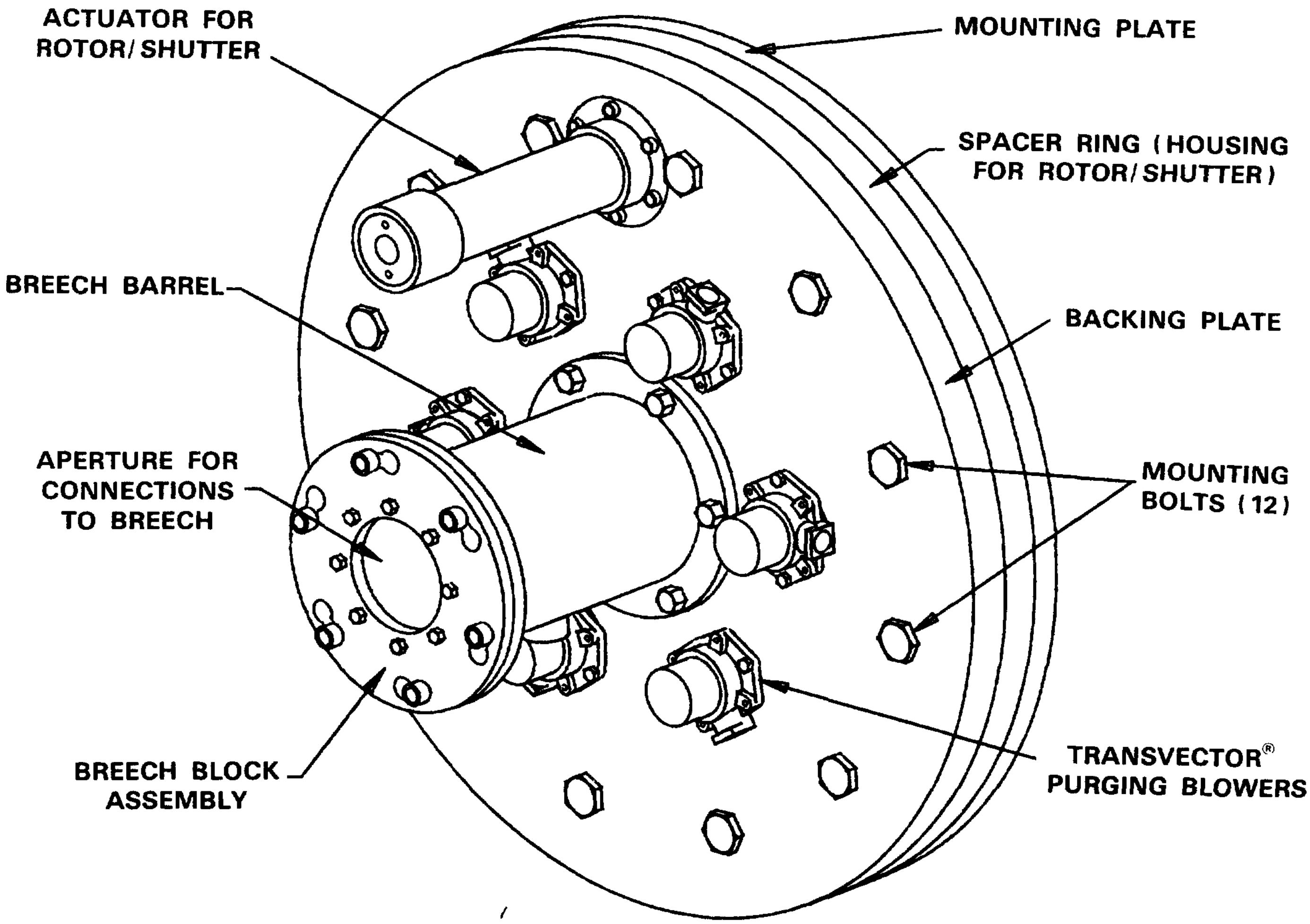

Figure 8b

PURGING SYSTEM, ASSEMBLED IN BREECH

ANNEX A

BLAST-TUBE TRIAL FIRING PROCEDURE CHECK LIST

BLAST TUBE TRIAL NO. ______________ DATE: ______________

PURPOSE: __________________________ PERSONNEL:

____

BTTO: ______________

TFO: ______________

OXY-ACETYLENE INITIATION MIXTURE

FFC: ______________

Concentration: ______________ Densitometer: ______________

Total Amount: ______________ Experimentor: ______________

DRIVING FUEL MIXTURE AMBIENT CONDITIONS:

Concentration: ______________ Pressure: ______________

Tank Pressure: ______________ Temperature: ______________

PRELIMINARY PREPARATIONS AND INSPECTIONS

D-1. **Densitometer personnel verify the functioning of the densitometer.**

D-2. **A rope barrier with a "radiation hazard" sign is set across the access to the test section.**

D-3. **Densitometer personnel remove the source-sting assembly from locked storage and mount the shielded assembly in the Blast Tube.**

D-4. Densitometer personnel install the source sting with the lead shield covering the sting head.

D-5. Densitometer personnel calibrate the densitometer.

D-6. Rope barrier with "radiation hazard" sign is removed from access point to test section.

7. BTTO inspects exposed gas lines, fittings, and cabling, and the exterior of the driver section for any indication of damage or poor condition.

8. FFC opens the required gas bottles and verifies that they are sufficiently full for the trial.

9. FFC evacuates all gas reservoirs.

10. BTTO confirms that the "spark-ignitor" is in place and functional by conducting a "SPARK TEST".

11. BTTO confirms that the hot wire is functional by conducting a "HOT WIRE TEST".

12. Initiation balloon is mounted.

13. Hot wire is properly mounted around the neck of the initiation balloon.

14. BTTO must confirm by close inspection that the balloon and hot wire are properly mounted.

FINAL CHECKS

15. BTTO checks with the experimentor to ensure that all experiment preparations are complete.

D-16. Densitometer personnel remove lead shield from source sting before each shot.

D-17. BTTO checks closure and locking of test section.

18. BTTO ensures that all diagnostic and flow equipment is ready and operating.

19. A barricade is set-up closing the access road to the immediate test area.

20. Activate flashing amber caution lights on roadway.

21. BTTO confirms positioning of the barricade by visual inspection and/or by radio.

22. All personnel report to proper firing stations and observation points except BTTO and FFC.

TRIAL PROCEDURE

23. FFC disconnects the vacuum pump and loads both the initiator gas reservoirs and the driving fuel dispersion tank.

24. BTTO removes the "firing plug" from the test pad.

25. BTTO and FFC proceed to Blast Tube Control Centre.

26. BTTO proceeds with final personnel check by radio call.

27. BTTO proceeds with final visual inspection.

28. BTTO requests permission to commence firing sequence by a radio call to FOS/ALPHA.

29. BTTO gives FFC permission to begin flowing initiation gases.

30. FFC notifies BTTO when initiation gases are loaded and advises when driving-fuel dispersion will be activated in the countdown.

31. BTTO instructs TFO to commence firing sequence.

FIRING SEQUENCE

32. TFO inserts "firing plug" into the instrumentation trailer firing module.

NOTE: Steps 33 to 35 should be synchronized according to TFO's countdown and will run continuously.

33. TFO starts countdown at T minus 15 seconds while announcing "T minus 15 seconds".

34. FFC activates driving fuel dispersion at the prescribed time and announces "fuel dispersing".

35. **FIRE at T equal zero**

POST TRIAL CHECKS

D-36. **BTTO confirms with Recording Operator/TFO that densitometer is still operational by presence of typical signal level on gauge output.**

37. **BTTO takes firing plug from TFO and returns it to the test pad module accompanied by densitometer personnel.**

NOTE: The chance of a dual fuel-air and radiation hazard occurring is considered to be very small, but if this situation were to arise the Fuel-Air Abort Procedure (Annex B) is first initiated and then the Radiation Emergency Procedures (Annex C).

38. **BTTO inspects the exterior of the driver-end of the Blast Tube for damage, fire, or leaking gas hazards and announces his assessment.**

39. **BTTO activates the blowers to clear the Tube of fumes.**

D-40. **BTTO gives densitometer personnel permission to proceed with densitometer inspection.**

D-41. **Densitometer personnel proceed with radiation hazard inspection.**

D-42. **Densitometer personnel declare result of densitometer inspection to BTTO. If no leakage is evident, proceed to step 43. If leakage is evident, the source sting assembly is bagged and labelled and contained as for leaking source material; Emergency Procedure described in Section 7 of Annex C are then followed.**

43. **If clear of all hazards, BTTO announces on the radio: "BLAST TUBE ALL CLEAR TO PERSONNEL".**

ANNEX B

FUEL-AIR ABORT PROCEDURE

1. Abort Situation

An abort of the gaseous-fuel detonation is the abrupt termination of the normal firing procedure at any point after the initial flow of gaseous fuel. Such an abort may be caused by such events as late-occurring instrumentation failure, any failure of the fuel charging system including rupture of the initiator balloon, or late realization that experiment preparations are incomplete or the blast may be hazardous to personnel or facilities. In all cases upon decision to abort by BTTO, BTTO instructs FFC to shut off all gas flows and announces the abort decision by radio.

If there is no serious compromise to safety or the planned experiment, the abort procedure would involve combustion (detonation or deflagration) of the gaseous fuel in the driver as described in Section 2 below. If there is any safety threat or compromise to the experiment by a combustion abort, it will be necessary to avoid combustion and purge the driver of all gaseous fuel as described below in Section 3.

2. Combustion Abort

In the case of this decision, BTTO notifies all stations to stand by, and instructs TFO to detonate the initiator balloon. TFO then attempts to detonate the initiator balloon by activating the spark-igniter. If the spark-igniter fails to ignite the mixture the first time, a second and, if necessary, a third attempt is made. Failing three attempts, TFO will activate the hot wire around the neck of the initiator balloon. In activating the hot wire, the neck of the balloon is burned off where it is secured to oxy-acetylene feed nipple, and one of two results will occur. If the initial problem was malfunctioning of the spark-igniter, the initiator mixture will detonate due to the hot wire. (This result has been confirmed repeatedly in separate tests). If the initial problem was incorrect initiator mixture concentration (i.e., the mixture concentration is outside the flammability limits), the deflation of the balloon will release the initiator mixture into the large volume within the Tube, effectively diluting the mixture to well below flammability limits and allowing a non-combustion abort, involving simple purging of the driver-section gases by activation of blowers.

3. Non-Combustion Abort

In the case of a non-combustion abort, the driver-section is purged of all fuel gases by remotely opening the blower ports in the breech and activating the blowers which will draw gases out the breech end of the driver. If the initiator balloon is still intact it will be first necessary to rupture the balloon. In this case, BTTO instructs FCC to activate air flow into the balloon. By doing so, the mixture will be diluted outside the flammability limits, and eventually the balloon will burst under the increased pressure. The driver section can then be purged as previously described.

ANNEX C

OPERATING AND EMERGENCY PROCEDURES FOR THE BLAST DENSITOMETER

The blast densitometer (also referred to as the blast density gauge) incorporated in the Blast Tube test section is to be used for time-resolved measurements of the total density of the blast-wave flow generated by the fuel-air explosion in the driver section. This instrumentation has been designed and tested to withstand the expected blast wave conditions. The system comprises a sensor assembly mounted at the wall of the Tube, with signal-conditioning electronics and power supply housed nearby external to the Tube, and a data recording system located in the instrumentation trailer, well away from the densitometer. Data transmission is via a cable system.

Figure C1 shows a sketch of the densitometer mounted on the Blast Tube wall. The densitometer used is an improved version of the use in large-scale blast tests in a field gauge stand configuration. For mounting in the Blast Tube the source-sting assembly is bolted directly to the interior wall and the detector assembly protrudes from the outside of the Tube.

When the blast wave passes between the source and detector, the increased air density in the blast wave causes an increased energy absorption of the beta energy resulting in a lower energy being detected by the scintillator-PMT assembly. The source of the ionizing radiation is a Premethium-147 beta source. The remainder of this section will contain procedures for the handling, installing and recovery of the beta source.

1. AREAS OF USE AND STORAGE

Radioactive materials are to be used as required for density measurements of the blast flow within the Blast Tube and as required for necessary calibration or other tests. Storage of the source-sting assemblies is under the ultimate control of the DRES Radiation Safety Officer (RSO). Authority to temporarily store sources in a secure area at the Blast Tube Control is granted by the RSO to the densitometer personnel who will apply appropriate AECB procedures as specified by the RSO. Around the site the source sting assemblies will be transported with the lead shield secure and entirely contained within a metal box. For transport out of the immediate test site, the boxes will be further contained within a sealable Type A storage container. AECB regulations require that radiation warning signs be located conspicuously on all sides of any vehicle transporting the material such that in the event of a vehicle accident those attending the scene will be warned.

2. SOURCE OF IONIZING RADIATION

Each source-sting assembly contains a Promethium-147 (PM-147) beta source. The present source strength is 1000 mCi. Promethium is a nearly pure beta emitter with an end-point energy of 0.224 MeV and a half-life of 2.5 years. The source is shown in Figure C2 and is a disc type, 22-mm in diameter and 6-mm thick, produced by Amersham Corporation. The active element is a wafer of hard vitreous enamel 15-mm in diameter. The source designation in PHC Q9680. The disc-source will be pre-mounted into its source-sting assembly shown in Figure C3 by the manufacturer, Ballistech Systems Incorporated, of Montreal. That assembly includes a lead shield which fits over the mounted source and is removed only when a measurement is required. This shielded assembly is transported in a metal shipping box which is further contained in a Type A shipping container.

3. REQUIRED CLOTHING AND MATERIALS

The following materials are required:

a. Materials for performing source inspection and leakage swab tests: mirror, tongs, swabs, solvent.

b. Clothing and apparel: coveralls, filter masks, goggles, rubber boots, disposable surgical gloves.

c. Materials for storage, decontamination and disposal: polyethylene bags/ties, tape, 5-gallon Type A waste-swab container, 5-gallon Type A source shipment container, lead vials, radiation warning signs/stickers, survey tape/stakes.

4. REQUIRED EQUIPMENT AND TOOLS

The following equipment is required:

a. Two beta-sensitive exposure meters capable of measuring the range 0.1 mR/hr to 100 mR/hr.

b. Thermo Luminescent Dosimeter (TLD) badges to be worn by any personnel involved with any aspect of the handling of the source.

c. Tools for the mounting of the source-sting assembly: hex wrenches, screwdrivers, threaded rod for securing lead shield.

d. Two hand-pumped water cylinders (11-ℓ capacity) and bucket for decontamination washing.

5. PROCEDURE OF WORK

The following procedures provide the methods by which the gauges are assembled and operated with full regard for personnel safety. These relate to only those operations where radioactive materials are involved above exempt quantities. No other hazardous materials or situations are expected beyond normal field work.

a. General Safety Precautions. All operations involving the use of the source material will be according to the professional practice expected from those who have been properly trained in the safe use of radioactive materials and use them on a regular basis. Only designated personnel, to be listed and approved by the DRES RSO, will be permitted to be in the vicinity of the gauge during the source-sting operations; the gauges will be suitably cordoned off during the mounting and demounting of the source-sting assemblies. Exposure monitors will be used to define areas where beta exposure to personnel exceed 0.1 mR/hr due to the source. In particular, care will be taken to prevent direct beta exposure to extremeties and eyes and to minimize secondary bremstrahlung exposure.

b. Specific Safety Precautions. The procedures for mounting and demounting the source-sting assembly, and the removal and replacement of the source shield have been developed to be simple and quick in order to minimize handling time and exposure risk. In the unlikely event of leakage, the source-sting assembly can be quickly shielded, demounted and contained in the field for closer examination later in the laboratory. Prior to a test the source-sting assemblies will be held separately under the control of the DRES RSO until the gauges are prepared in the field. The installation procedure is straightforward as follows:

5.1 Mounting of the Source-Sting Assemblies

i) Determine that all mechanical and electronic work has been completed on the gauge head and that the only remaining operations are those requiring the installation of the source-sting assembly.

ii) Designate the densitometer personnel (one operator, one assistant) responsible for mounting the source-sting assembly onto the Blast-Tube wall. These personnel will be fully prepared with proper attire, materials and equipment.

iii) The designated operator will go to the storage site for the source-sting assembly in its shipping container. The container is then taken to the Blast Tube and a rope barrier is erected to restrict any access to the operation. Signs warning of the radiation hazard will be posted and visible from any approach.

iv) Set a beta-sensitive detector/monitor so that the area around the gauge head will be monitored and provide an active indication to the operator.

v) Remove the lid of the container and inspect the source-sting assembly for obvious damage. Using gloved hands, removed the source-sting assembly from the container, holding it by the base. Do this with care and ensure adequate monitoring of exposure by the operator. Note that the active face of the source is still contained by a lead cover shield. Test for contamination with swabs and meter. If none is found, proceed to the next step; should contamination be present, proceed to Section 7, Emergency Procedures.

vi) Carefully mount the source-sting assembly on the inside of the Blast Tube wall as follows. Place the base plate of the source-sting into the recess provided in the wall. Use the mounting bolts to firmly secure the sting assembly (Figure C1). Note that the active source face remains shielded.

vii) Once mounting operations are complete, the rope barrier and signs are removed, however a 'Radiation Hazard' sticker will be left on the gauge at all times when the source is mounted. Survey the area within 5 meters of the gauge head using exposure monitors for post-shot comparison.

5.2 Removal of Source Shield

i) The source sting is pre-assembled with a lead cover sleeve which fits over the head of the source sting to completely shield the source. This shield will be removed to expose the active source face only when measurements are required such as during calibrations, system checks and Blast Tube shots. To remove the shield, loosen the locking bolt on the shield and use the threaded rod to remove the lead shield from a distance.

ii) Holding the mirror with tongs, visually inspect the surface of the source cover screen for obvious damage. Test for contamination with swabs and meter. Should contamination be present, proceed to Section 7, Emergency Procedures. Note that due to the physical configuration of the mounted source behind its screen, even with the shield removed significant exposure can result only if body parts are placed between the source and detector.

iii) Two types of field calibration systems may be employed. In the first type a simple frame with several windows of increasing thicknesses of mylar film is passed between the source and detector to provide a known sequence of mass absorption. In the second type, a chamber will be secured between the source and detector. The chamber will then be pressurized with air to provide a known static density increase.

iv) After calibrations or other system checks, the lead shield will be replaced over the head of the source sting by use of the threaded rod and securing of the locking bolt.

5.3 Post-Shot Recovery

i) Immediately following the shot and before re-entry into the Blast Tube, the recording station should be accessed to monitor the output from the densitometer. A dramatic change in output, particularly loss of signal, may warn of possible damage or loss of the source. However, there are several possible causes for such changes in output not related to source damage. Personnel should then deploy to re-enter the test bed fully equipped and clothed for a careful radiation survey.

ii) Approach the gauge site and inspect at a distance for obvious damage to the structure. If damage is evident to the source-sting assembly, proceed to Section 7, Emergency Procedures. If there is no obvious damage, approach within 5 meters of the gauge from the open end of the Tube monitoring radiation levels carefully while advancing. If contamination is evident, proceed to Section 7, Emergency Procedures. If none is evident, proceed to the gauge and use swabs and meter to inspect the gauge head, source sting, and the face of the source screen for contamination.

iii) If the source shows no sign of leakage, proceed to the next step; otherwise, proceed to Section 7, Emergency Procedures.

iv) Secure the lead cover shield over the head of the source sting using the threaded rod and secure the locking bolt. Demount the source-sting assembly by unbolting the base plate of the sting from the wall of the Blast Tube. Place the source-sting assembly into a plastic bag and set into its metal container. The source is now secure and can be returned to the secure storage on site. The source-sting containers will be subsequently packed into Type A container for shipment to Bldg. 13 once trials are finished.

6. MATERIAL DISPOSAL

a. Decontamination. In the event of contamination from a source, swabs and other cleaning materials which may have low-level activities will be bagged and will require disposal.

b. Storage. A 5-gallon Type A storage container which holds all source-sting assemblies is required to be stored under the authority of the RSO at Bldg. 13 when trials are not underway at the Blast Tube. During a trial series the sources may be stored in a secure and labelled area at the Blast Tube site.

c. Waste Disposal. In addition to possible decontamination material, in the unlikely event of severe damage to a source, there may be a requirement for disposal of damaged sources.

7. EMERGENCY PROCEDURES

An emergency would occur in the unlikely event of the source being broken up or partially dispersed during a blast or any case during shipment or handling in which contamination is found indicating leaking source material. The two densitometer operators on site will be responsible for emergency procedures.

7.1 Loss of the Source

Complete loss of the source is extremely unlikely due to its mounting, but, after visual inspection at the site, if the source or the entire source sting has been dislodged, then an area survey is required to locate the source.

a. A zone will be cordoned off with survey tape and inspected by a team equipped with beta monitors with the possible support of metal detectors. The source is a nearly pure beta emitter but also emits a small amount of bremstrahlung which may be detected over a meter in distance. The initial search zone will include the inside of the Blast Tube and end-wave eliminator. Should the source not be found the zone will be extended to an area 2 meters to either side of the open end of the tube and 10 meters from the end; this zone may have to be further extended if the second search is unsuccessful. If significant difficulty is encountered in locating a lost source, RSO will be notified immediately; if all search efforts are unsuccessful, notification to AECB will be made through RSO.

b. Once the source is found, then it should be picked up with tongs, sealed in a lead vial, sealed in a plastic bag, then placed in its source-sting container. Another plastic bag should be used to seal the container which can then be placed in a Type A container for subsequent disposal. After the removal of the source, the surrounding area must be checked for any activity and any contaminated earth or material bagged and disposed.

7.2 Leakage of Source

Leakage of the source may occur due to unusual damage during shipment or handling, or unusual blast damage during the course of a test.

a. Using meters and swabs where necessary isolate the extent of the contaminated area and cordon this zone with rope barriers and 'Radiation Hazard' signs.

b. This area is to be decontaminated and the source-sting assembly contained. Bring the source-sting container, a 5-gallon container for the leaking source-sting assemblies, a 5-gallon contaminated-waste container, and bags/seals for collection of contaminated materials. Note that all personnel must be properly clothed with coveralls, gloves and rubber boots; filter masks must be worn if it is suspected that contaminated material has been dispersed in the air. All materials and components must be monitored and wiped clean of any activity before being touched.

c. If not already in place, secure the lead shield over the head of the source sting using the threaded rod and locking bolt. Demount the source-sting assembly by unbolting it from the wall of the Blast Tube. Bag and seal the entire assembly and place in the source-sting container. Bag and seal the container, label as to its origin and place in the 5-gallon Type A storage container. The storage container must be labelled as for 'Leaking Source Material'. As appropriate, the sting assembly will be examined later in a laboratory or disposed as waste material.

d. Swab and decontaminate any surrounding structures, components, or materials until all activity if removed and bagged in the 5-gallon waste-swab container.

e. The waste container and the leaking-source container are transferred to the RSO. Final disposition of leaking source-sting assemblies will be decided after consultation with the experiment Project Officer.

f. All personnel involved with the decontamination will be closely inspected for contamination. Any contaminated clothing will be removed and bagged; the bags will be sealed and labelled with 'radiation hazard' tape and then placed at the disposal of the RSO. Any skin that is contaminated will be thoroughly washed down using a portable hand-pump water cylinder and wash bucket. All decontaminated gauges will be dismantled and returned to storage by arrangement of the experiment Project Officer.

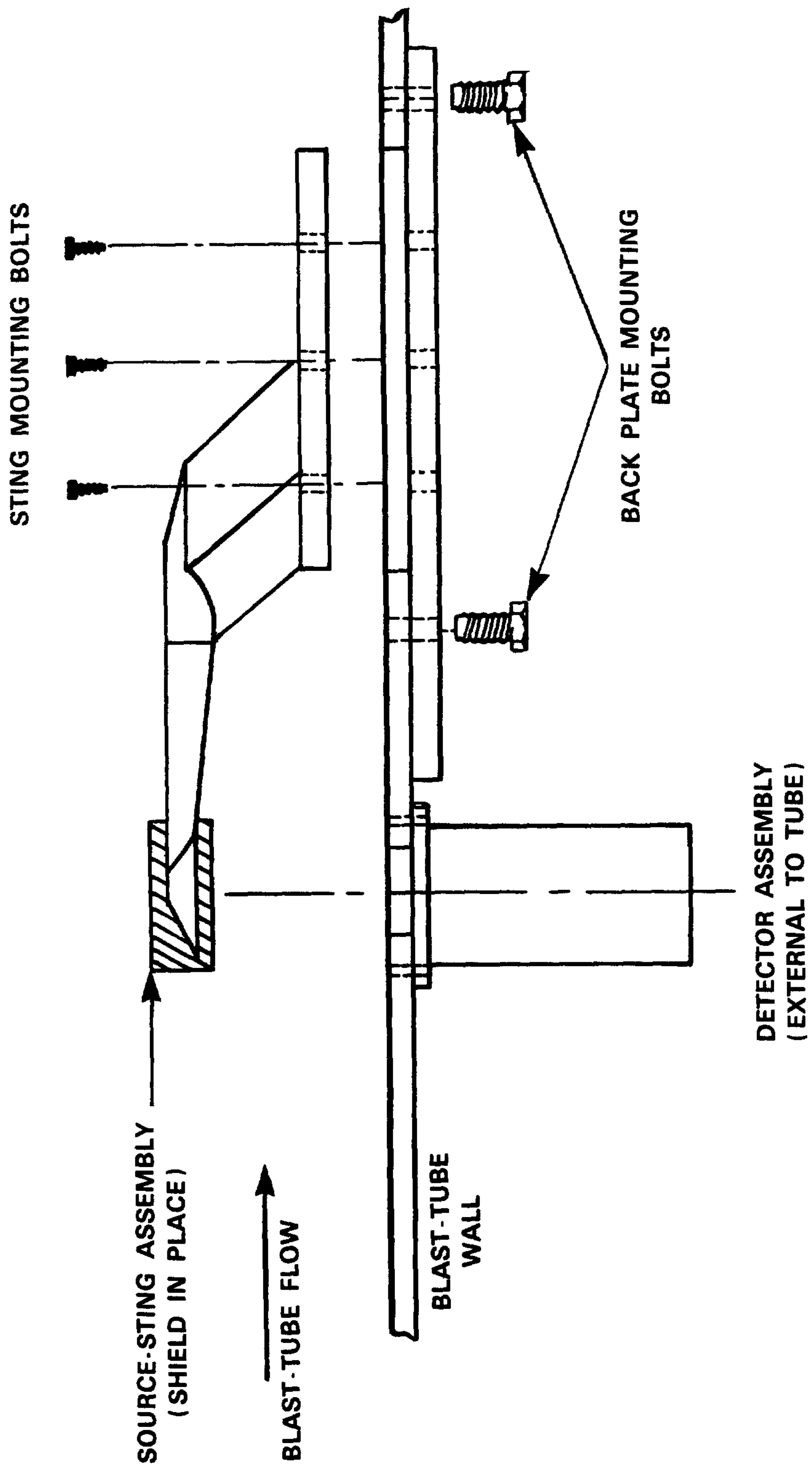

Figure C-1

MOUNTING ARRANGEMENT OF A BLAST DENSITOMETER IN THE WALL OF THE BLAST TUBE

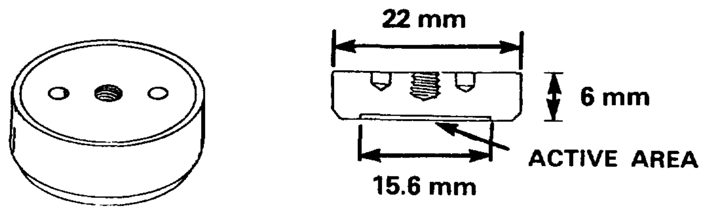

Figure C-2

1000 mCi Pm-147 BETA SOURCE FROM AMERSHAM, PHC Q9680

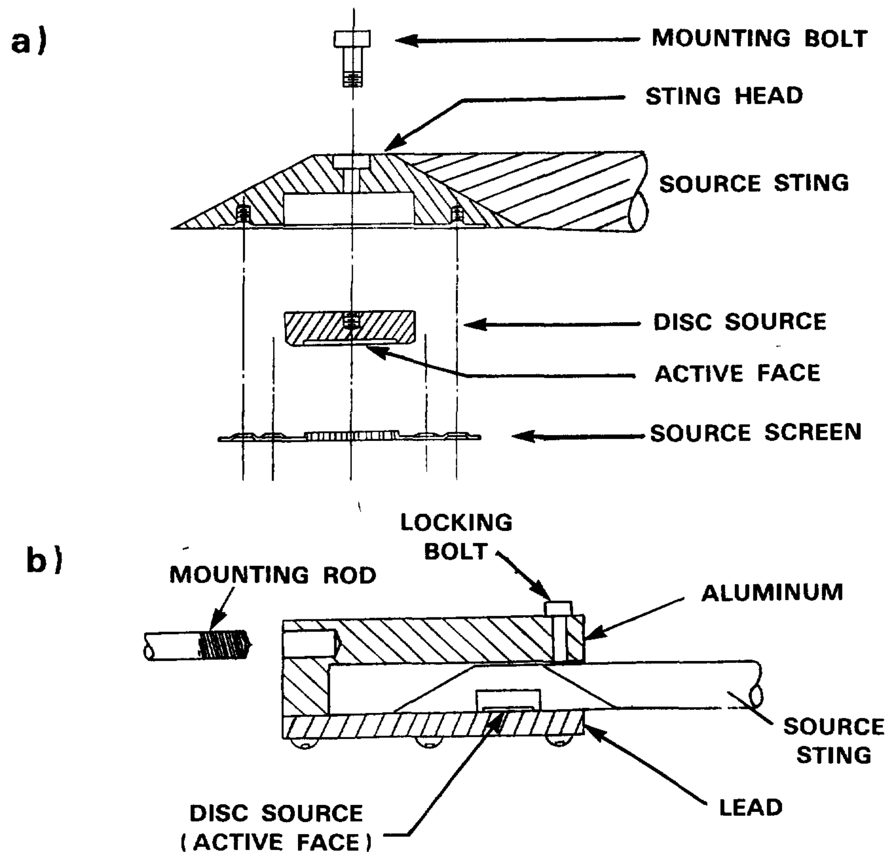

Figure C-3

a) DETAIL OF THE PRE-ASSEMBLED HEAD OF THE SOURCE STING IN WHICH THE SOURCE IS BOLTED BEHIND AN ALUMINUM SCREEN

b) LEAD COVER SHIELD WHICH FITS OVER THE STING HEAD

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13. ABSTRACT

The DRES Blast-Tube facility has been established to allow intermediate-scale blast experiments for the investigation of blast-wave flows and the response of structures and materials to blast loading from explosions in air. The Blast Tube is essentially a 50-m length of steel pipe of 1.8-m diameter with one end which tapers down to a 0.45-m closed end cap. A cloud of fuel-air explosive is dispersed within the tube at the closed end and detonated to create a blast wave which travels down the tube to the test section where required measurements are obtained.

To allow safe and effective operation of the Blast Tube, firing and safety procedures have to be established. This report describes the firing procedures and safety regulations to be used in the operation of the Blast Tube, including detailed descriptions of the operations required for dispersing and detonating the fuel-air cloud. Also described is the operation of special instrumentation for measurements of density-time records of the blast-wave flow which makes use of a radioactive beta source.

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KEY WORDS

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SHOCK TUBE
BLASTWAVE
FUEL-AIR EXPLOSIVES

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