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Simplified eight-shot pneumatic pellet injector for plasma fueling applications on the Princeton Beta Experiment and on the Advanced Toroidal Facility*

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ABSTRACT

Plasma fueling via injection of solid hydrogenic pellets has expanded the operating range for tokamaks and stellarators to higher densities than attainable with gas puffing. Pellet injection has also resulted in improved plasma energy confinement in tokamak discharges for which the pellet or pellets penetrate deep into the plasma core. The eight-shot pneumatic pellet injector described herein has been developed for use on the Princeton Beta Experiment (PBX) and on the Advanced Toroidal Facility (ATF) for routine plasma fueling and for confinement optimization studies. The injector is based upon the so-called "pipe-gun" concept, which generates deuterium and hydrogen pellets by direct condensation in the gun barrel tubes, segments of which are cooled below the hydrogen triple point temperature by contact with a liquid helium cooled block. Control of the pellet length is achieved both by regulating the deuterium fill pressure and by establishing temperature gradients along the barrel tubes. This injector features eight independent gun barrel assemblies mounted around the perimeter of a single cold

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block, each coupled to an ORNL-designed fast propellant valve. Thus, the injector is capable of injecting arbitrarily programmable sequences of up to eight pellets of sizes ranging from 1 mm to 3 mm in at speeds up to 1500 m/s.

I. INTRODUCTION

Pneumatic pellet injectors based on the so called "pipe gun" concept, first developed by Lafferanderie and Claudet,[1] are finding use in pellet injection experiments on magnetic fusion devices as well as in various high-speed pellet injector development projects.[2-4,10] The injector described herein was designed for use on short pulse fusion research experiments, such as the Princeton Beta Experiment (PBX) and the Advanced Toroidal Facility (ATF). These experiments will require injection of sequences of several pellets of various sizes over a one second discharge period; flexibility in terms of variable pellet size and repetition rate, and injector performance reliability are the key hardware performance characteristics required for optimizing plasma parameters.

II. DESCRIPTION OF EQUIPMENT

An assembly drawing on the eight-shot injector is depicted in Fig. 1. The major components of this injector are (1) the vacuum jacket, (2) the main and auxiliary liquid-helium cooled copper blocks, (3) the eight gun barrel subassemblies, (4) the interface spool piece subassembly, which includes the barrel to guide tube alignment fixtures, the fill isolation gate valves and the pellet timing and photographic diagnostics, (5) the housing rear plate, which incorporates the eight fast propellant valves and eight sets of propellant and projectile gas fill valves (not shown), (6) the top plate, which incorporates the cryogen fill, control, and outlet feedthrus, (7) the positioning platform, and various electronic power supplies and control systems.

The vacuum enclosure is a reduced scale copy of the design used in the pneumatic injector developed for the Joint European Torus experiment.[5] It was fabricated from a 0.75-in-thick aluminum plate welded together into a frame for mounting the top, rear, left, and right side cover plates, and the interface spool piece assembly. The main and auxiliary helium-cooled copper blocks were fabricated from OFHC copper. Cooling is provided by pressurized cold helium gas flowing through 0.19-in-deep cooling channels machined into each block. Cavities were machined into the block faces in order to reduce the liquid helium required for cooldown; a ring of lead (90° K Debye temperature) was attached to the larger block to provide a net 20 joule/degree-K thermal mass at low temperatures. The blocks were mounted with brackets on a 2-in-diam 0.63-in-thick support post (stainless steel) welded to a rotatable Varian flange, facilitating alignment of the gun barrels with the spool piece assembly.

A gun barrel subassembly is shown in Fig. 2. A VCR fitting brazed to the breech end of the barrel tube serves as the coupling to the propellant valve. Tapered transition sections bored into these fittings adapt the 3/16-in-diam propellant valve outlet tubes to the 0.040, 0.080, and 0.120-in-diam gun barrels. Further down the barrel tube, a copper disk is attached with silver-solder. This disk cools the adjacent segment of the barrel tube below the pellet gas triple-point temperature; deuterium fill gas contacting this cold segment condenses on the tube wall and solidifies, forming a pellet. The length of the pellet is regulated by establishing temperature gradients along both the muzzle and breech ends of the barrel tube using copper sleeves which are themselves anchored to a gradient regulating bracket (Fig. 1). The copper disk described above is captured in a T-shaped copper barrel mounting bracket which is bolted to the main helium-cooled block. Indium foil is used in both the disk-to-bracket and bracket-to-block joints for good thermal contact. Copper powder impregnated grease is applied under the copper sleeves to provide thermal contact to the barrel tube. Two stainless steel end brackets fastened to the T-bracket with stainless screws and nylon washers provide mechanical support for the barrel tube. The muzzle end of the barrel tube is silver soldered into an alignment collar which is captured in a photo-diagnostic piece (Fig. 3). The barrel tubes in the PBX unit are bent 1.877° towards the spool piece assembly axis, resulting in a pellet trajectory confluence at 108 inches from the interface spool piece. This aiming is achieved by mating the photo-diagnostic pieces to Quick-FLange stubs welded into precision holes machined in the upstream end plate of the interface spool piece assembly. Fiber-optic cables (Fig. 4) are used to couple in a light beam which, when interrupted, generates a timing pulse indicating the pellet's passage out of each barrel; separate fiber cables couple in the beam from a TEA nitrogen-pumped dye laser used for pellet illumination in obtaining shadowgraphs. Downstream, the photo-diagnostic pieces are connected to isolation gate valves (VAT Model 12128-KA44) fitted with ISO-KF flanges. The precision alignment of the valve flanges, together with the close tolerance fit between the photo-diagnostic piece and the isolation valves, results in accurate pointing of the gun barrel tubes relative to the isolation valve outlet ports. Into each gate valve is inserted a guide tube centering collar, which completes the alignment of each guide tube with its corresponding barrel tube. Gas vent slots machined into the centering collars allow the propellant gas to pass into the guide tube assembly enclosure.

The injector housing rear cover serves as the mounting plate for the propellant gas fast solenoid valves, which are of the type described in Ref. 6, and for the propellant and pellet fill gas solenoid valve manifold (Fig. 5a). The propellant fill valves are 3000 psi balanced-poppet valves (Marotta Valve Model MV100) while the pellet gas fill and bypass valves are Skinner Model B2DA1175 valves. The top plate feedthrus are visible in Fig. 5b; these include a bayonnet inlet port for helium coolant, feedthrus for motorized helium flow-regulating valves, and outlet ports for the helium exhaust. The motor-driven valves are used to throttle the helium flow to within the temperature regulating range of Lakeshore Cryotronics temperature controllers, which power nichrome wire heaters wound around each cold block. Lakeshore Model DT-470-CU-12 silicon diodes are used to measure the cold block and gradient regulating bracket temperatures. One hundred ohm carbon resistors epoxied to the gradient regulating brackets are powered by constant voltage supplies which can supply up to 3 watts of heat. All of the electrical feedthrus for the heaters and diode thermometers are mounted on the upstream plate of the interface spool piece. This allows for disassembly of the injector and removal of the cold block and barrel assemblies following separation of the VCR couplings connecting the propellant valves to the barrel tubes.

The injector positioning subassembly, which allows three-dimensional positioning of the gun with respect to the pellet transport line, is identical to the unit used in the Deuterium Pellet Injector described in Ref. 7. The injector is controlled using a control system built with Allen-Bradley Model SLC-100 controllers and expansion modules. Both sequential and parallel fill programming is available with both flow and fill pressure regulation, accomplished with MKS Instruments Model 221-AA pressure sensors, a Model 1258B flow sensor and regulating valve, and a Model 250B flow or pressure controller. The gradient bracket temperatures are scanned using a Lakeshore Cryotronics Model 208 eight-channel diode readout unit. The fast propellant solenoid valves are powered from capacitor power supplies originally designed for the Repeating Pneumatic Injector (Ref. 8).

III. EIGHT-SHOT PERFORMANCE

For initial testing purposes, the PBX unit was outfitted with 1- 2-, and 3-mm-diam barrel tubes: shadowgraphs of three deuterium pellets formed and accelerated in theses tubes are shown in Fig. 6. All three pellets were accelerated with room temperature hydrogen propellant gas at 1200 PSIG plenum pressure. The speeds for all three pellets were 1200 m/s +/-10%; by comparison, the idealized gun theory (Ref. 9) value for 3 and 6-mm-long projectiles are 1450 m/s and 1230 m/s, respectively. The invariance in the pellet speed must reflect the offsetting effects of differences in pellet mass vs differences in barrel tube chambrage. The capacity for varying pellet size before changing fill conditions is illustrated by the shadowgraphs (Fig. 7) of three pellets formed in a 1-mm-diam barrel tube at 20, 35, and 50 Torr fill pressure, respectively. Figure 8 shows a composite plot of the range of pellet masses covered in the first four runs, using 1-, 2-, and 3-mm-diam barrel tubes filled either from the breech side only or from both sides. One can see that by using three or perhaps four different barrel sizes, the entire pellet mass range from 1 to 30 Torr-l is accessible merely by changing the fill conditions. Additional size control obtained by sequentially filling the barrel tubes should be possible.

REFERENCES

1. J. Lafferanderie, preesented at the International Pellet Fueling Workshop, La Jolla, California, October 30-November 3, 1985.

2. O. Lazare, "Injection De Glacons De Deuterium Dans Le Tokamak TFR," These, Universite De Paris-Dud Centre D'Orsay.
3. D. D. Schuresko et, al., "Development of Hyrogen Electrothermal Accelerator for Plasma Fueling," J. Vac. Sci. Technol. A5, p. 2194, (1987).
4. S. K. Combs et. al., "Simple Pipe Gun for Hydrogen Pellet Injection," Rev. Sci. Instrum. 57, 2636 (1986).
5. S. K. Combs et. al., "A Three-Barrel Repeating Pneymatic Pellet Injector for Plasma Fueling of the Joint European Torus," J. Vac. Sci. Technol. A6, 1901 (1988).
6. S. L. Milora et. al., Fast-Opening Magnetic Valve for High-Pressure Gas Injection and Applications to Hydrogen Pellet Fueling Systems," Rev. Sci. Instrum. 57, 2356 (1986).
7. S. K. Combs et. al., "An Eight-Shot Pneumatic Pellet Injection System for Tokamak Fusion Test Reactor," Rev. Sci. Instrum. 58, 1195, (1987).
8. S. K. Combs et. al., "Repeating Pneumatic Hydrogen Pellet Injector for Plasma Fueling," Rev. Sci. Instrum. 56, 1173 (1985).
9. D. D. Schuresko et. al., "Performance Characterization of Pneumatic Single Pellet Injection System," J. Vac. Sci. Technol. A1, 959 (1983).
10. H. Sørensen et al., "Simplified Pipe Gun," Rev. Sci. Instrum. 58, 2336-37 (1987).

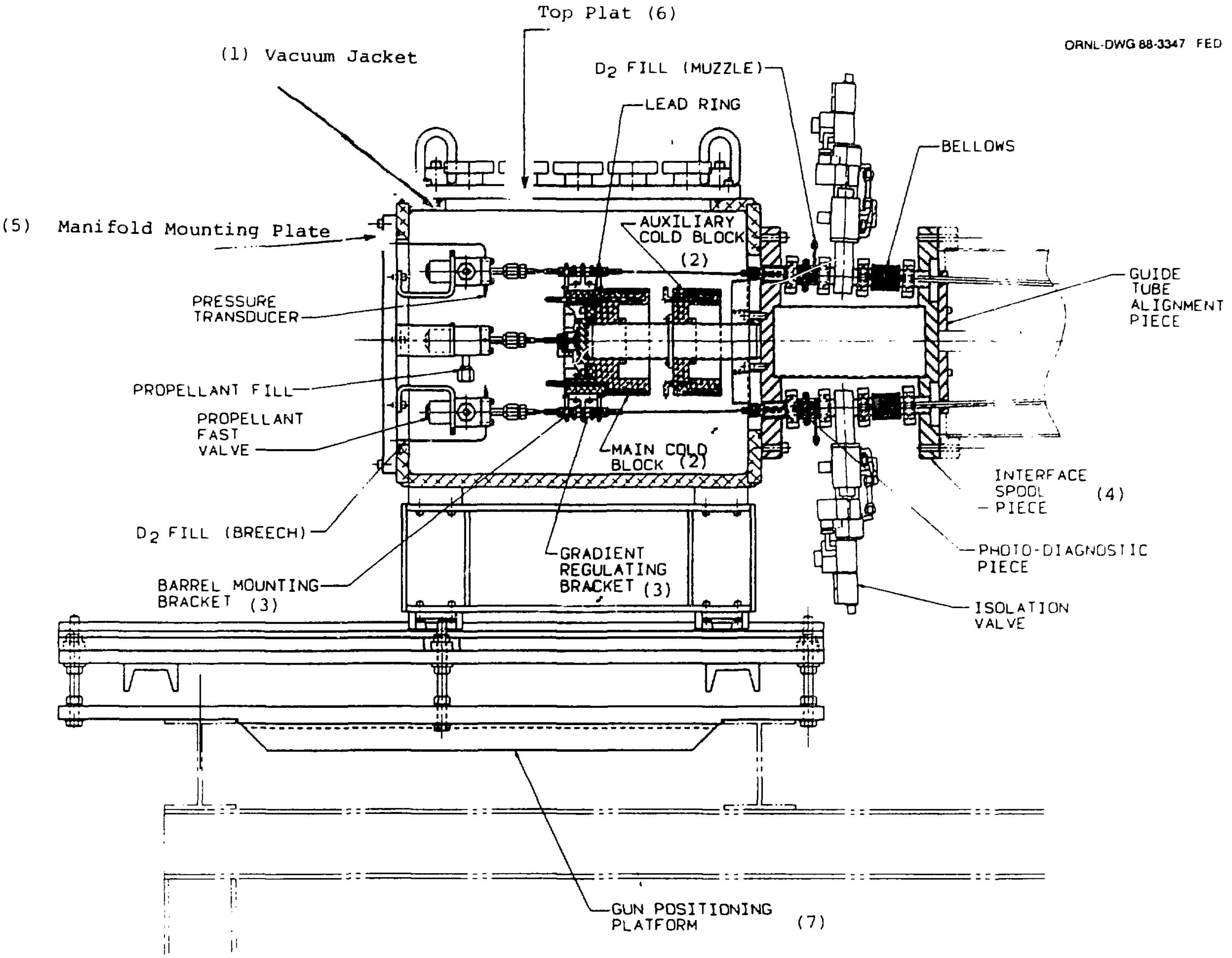
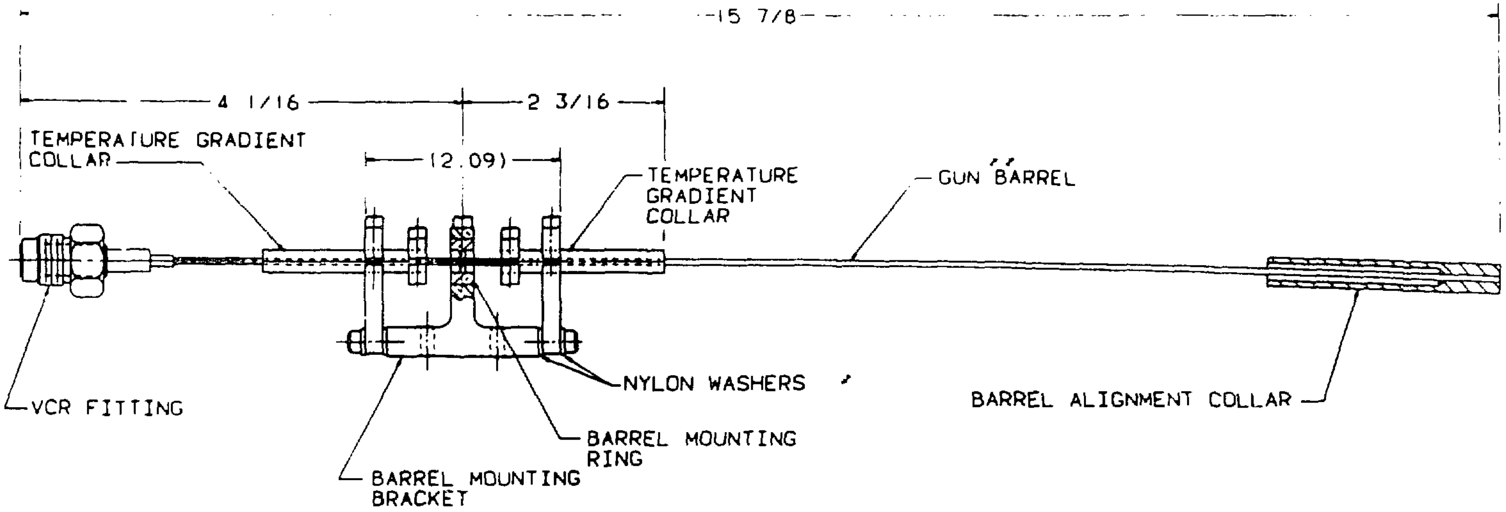

ORNL-DWG 88-3347 FED
Top Plat (6)
(1) Vacuum Jacket
D2 FILL (MUZZLE)
LEAD RING
BELLOWS
(5) Manifold Mounting Plate
AUXILIARY COLD BLOCK (2)
GUIDE TUBE ALIGNMENT PIECE
PRESSURE TRANSDUCER
PROPELLANT FILL
PROPELLANT FAST VALVE
MAIN COLD BLOCK (2)
INTERFACE SPOOL PIECE (4)
D2 FILL (BREECH)
PHOTO-DIAGNOSTIC PIECE
GRADIENT REGULATING BRACKET (3)
BARREL MOUNTING BRACKET (3)
ISOLATION VALVE
GUN POSITIONING PLATFORM (7)

Figure 1.

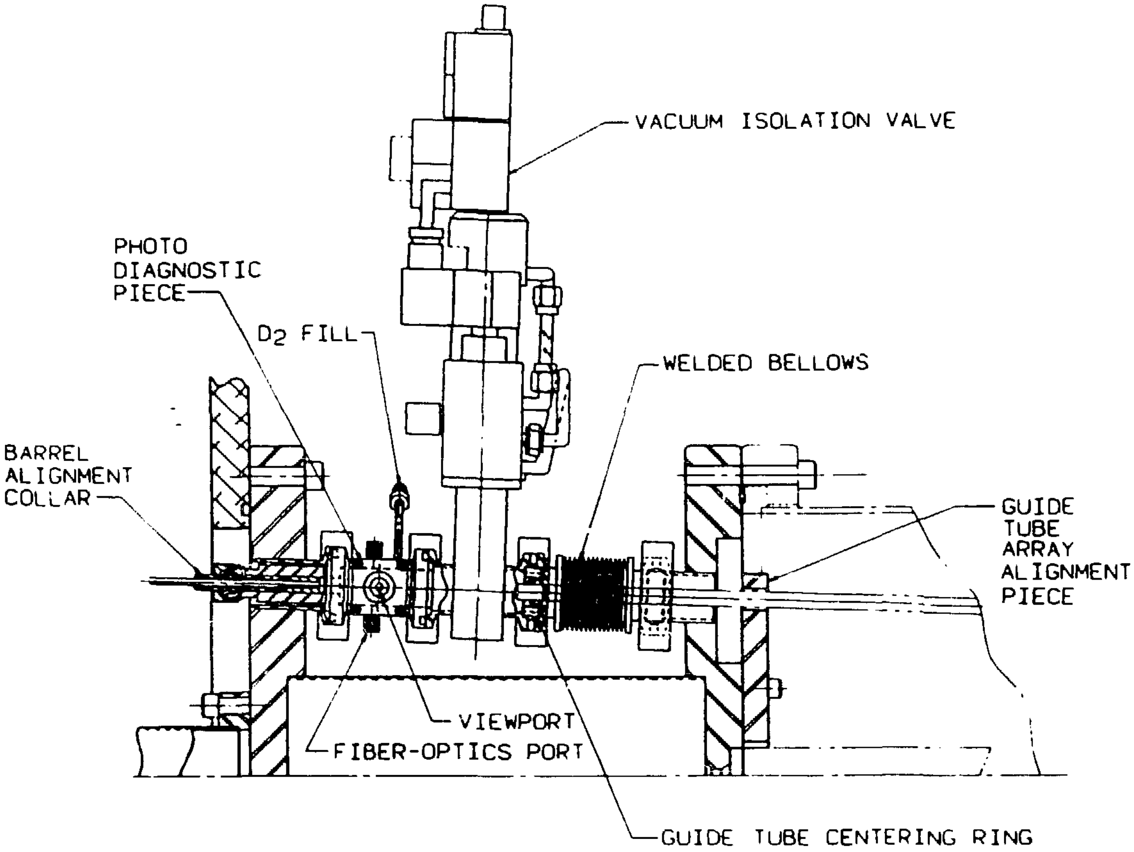
ORNL-DWG 88-3348 FED



BARREL ASSEMBLY

Fig. 2

ORNL-DWG 88-3350 FED



INTERFACE SPOOL PIECE ASSEMBLY

Fig. 3

ORNL-DWG 88-3349 FED

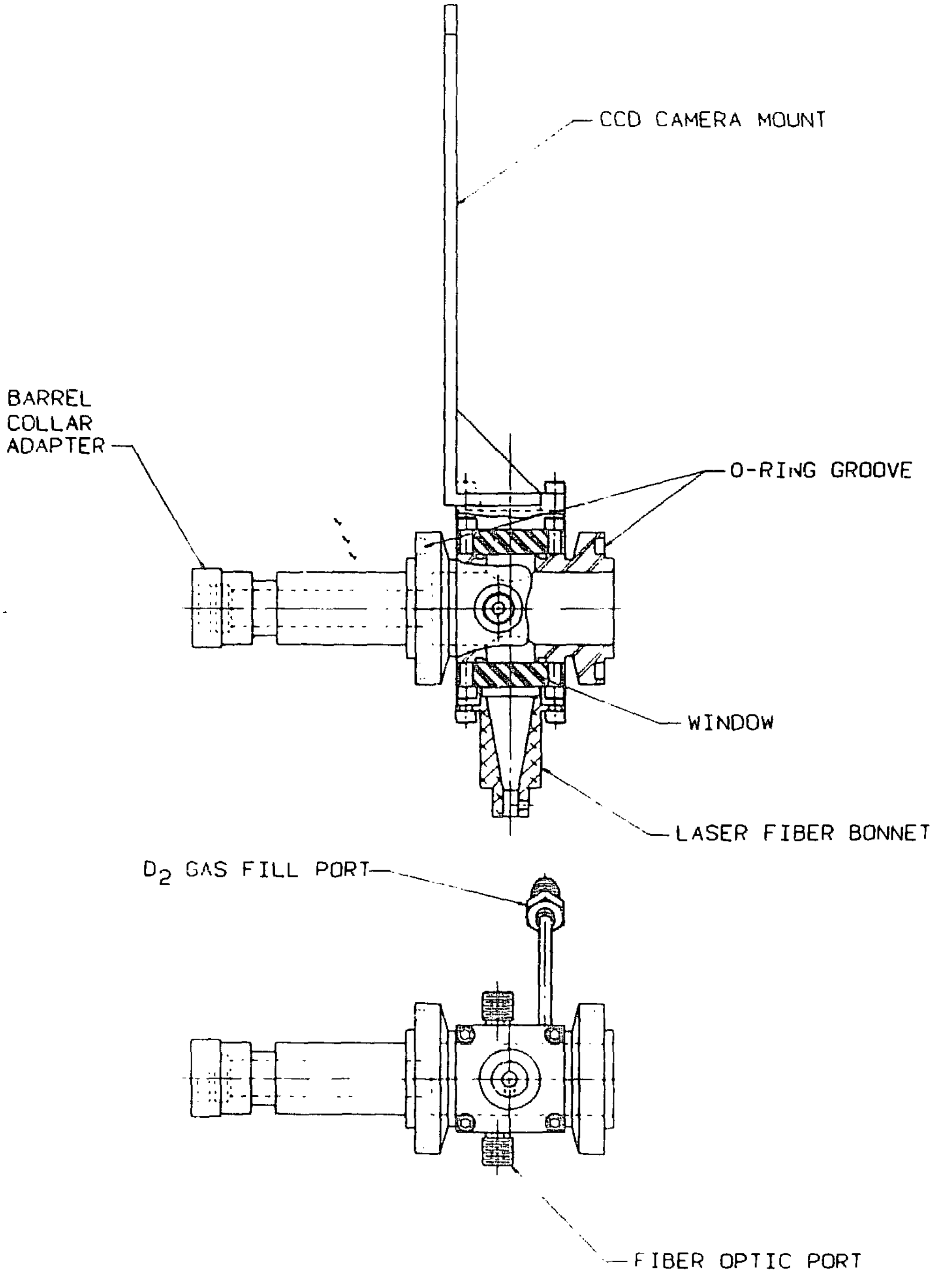
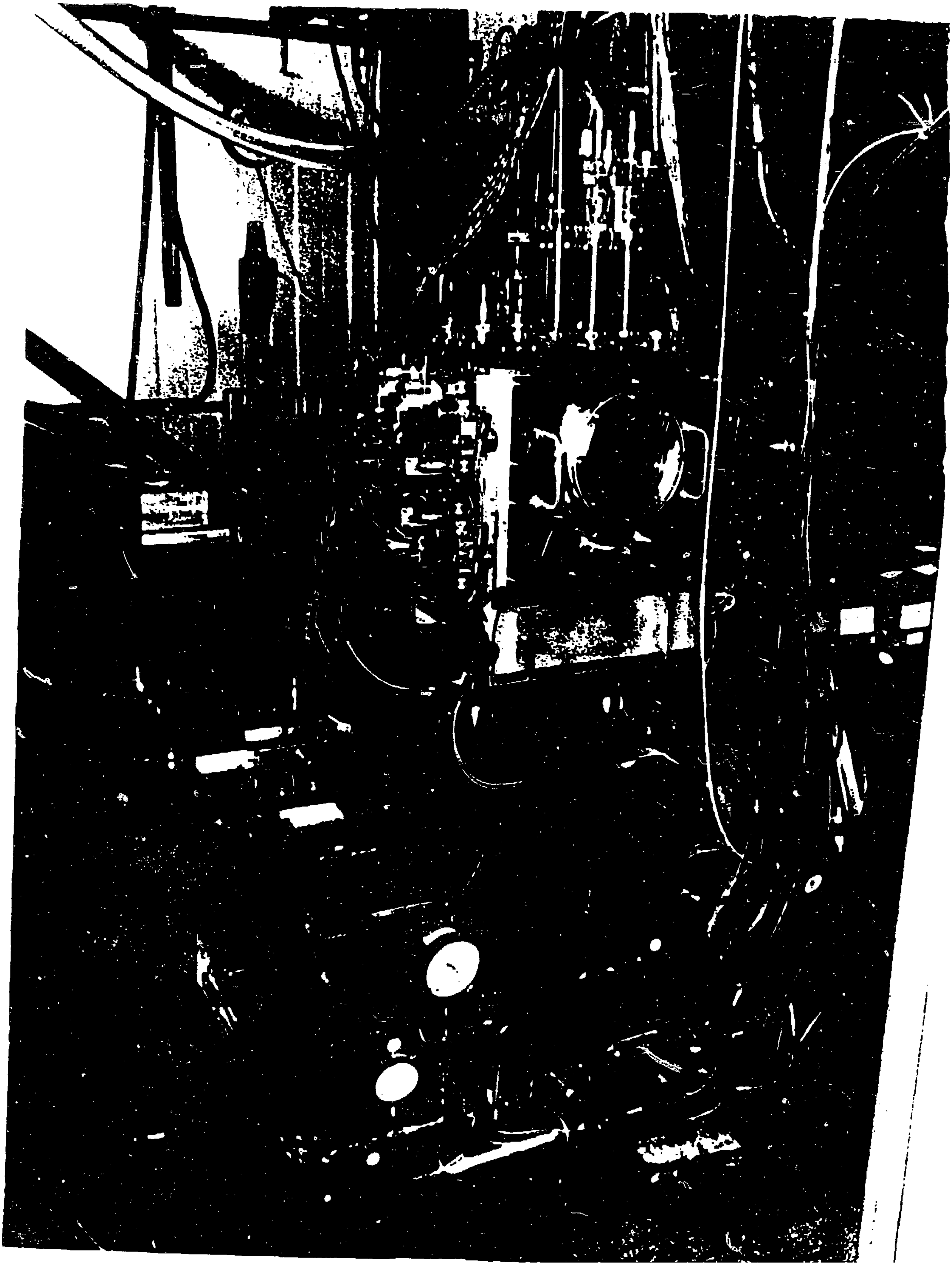


Fig. 4



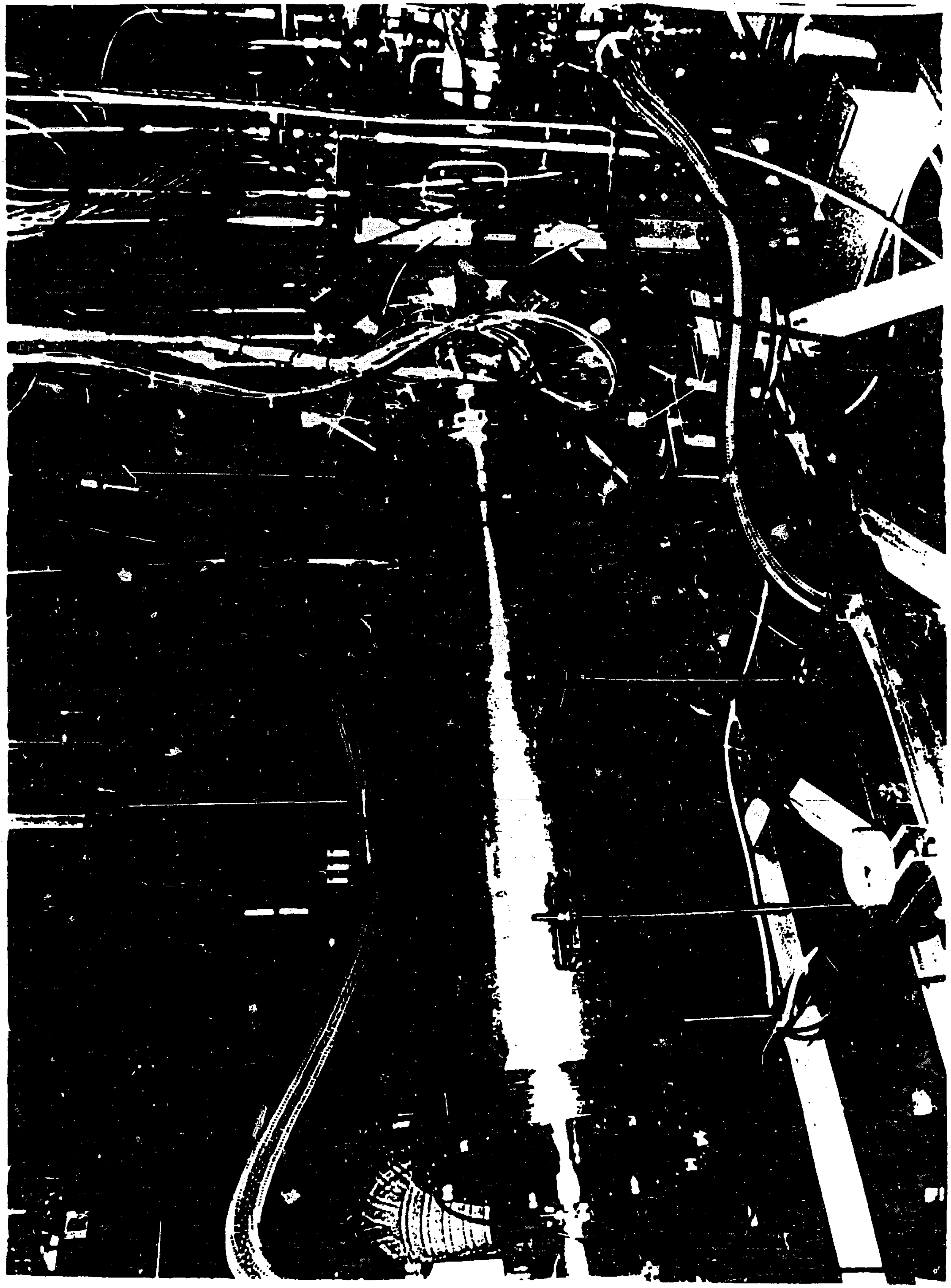


Fig. 5b

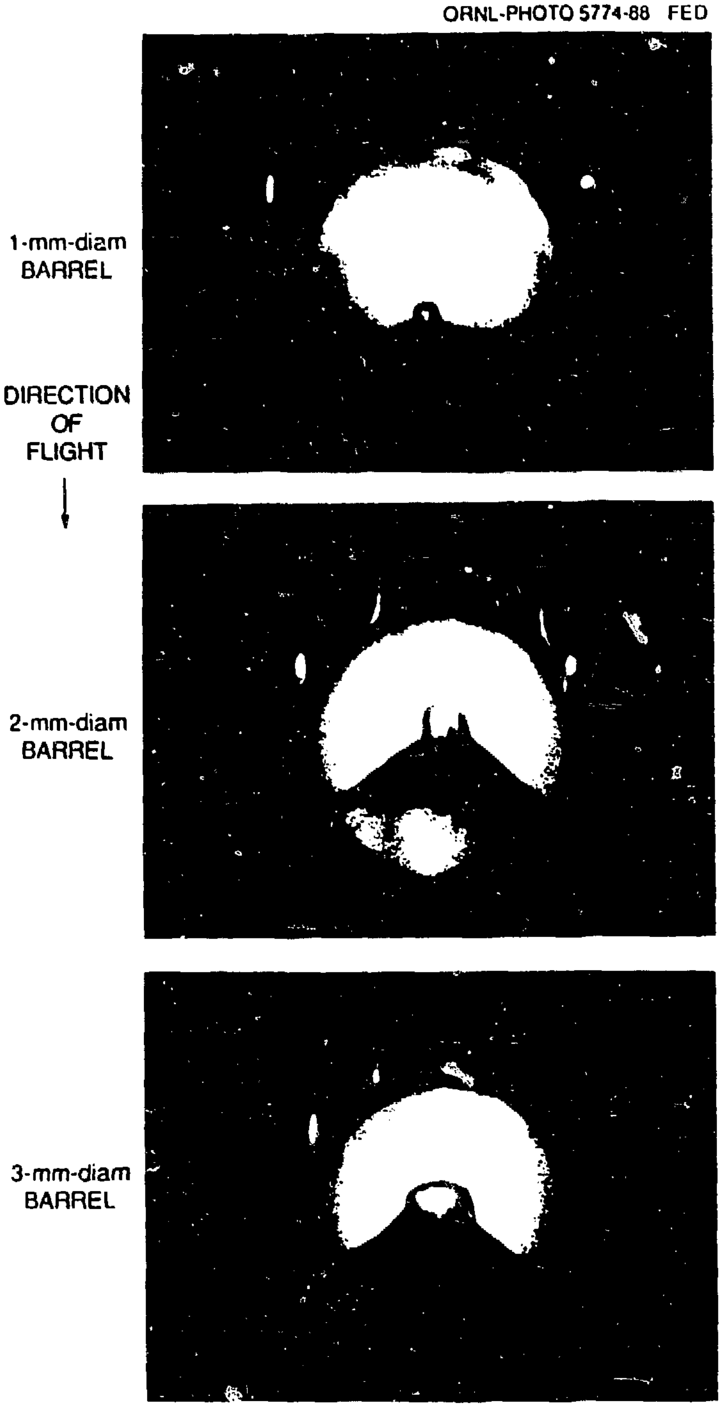

ORNL-PHOTO 5774-88 FED
1-mm-diam BARREL
DIRECTION OF FLIGHT
2-mm-diam BARREL
3-mm-diam BARREL

Fig. 6

ORNL-PHOTO 5773-88 FEL

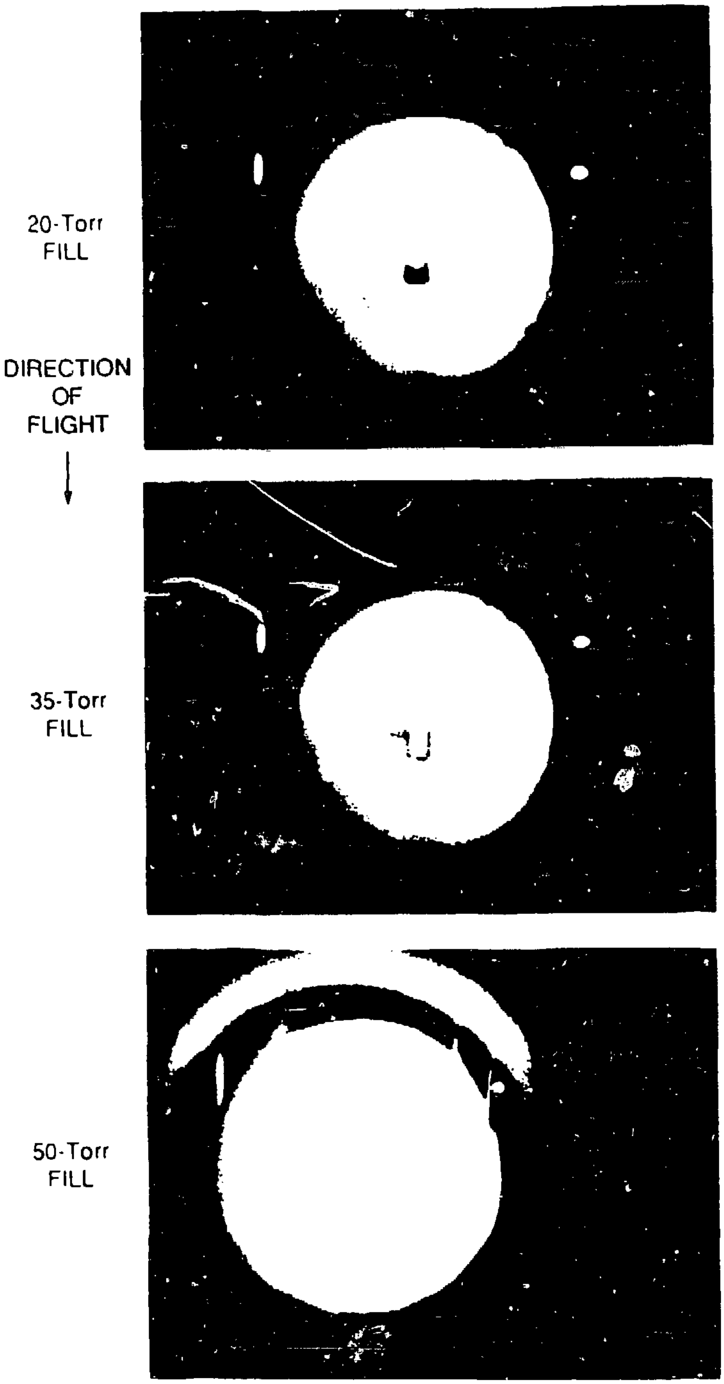
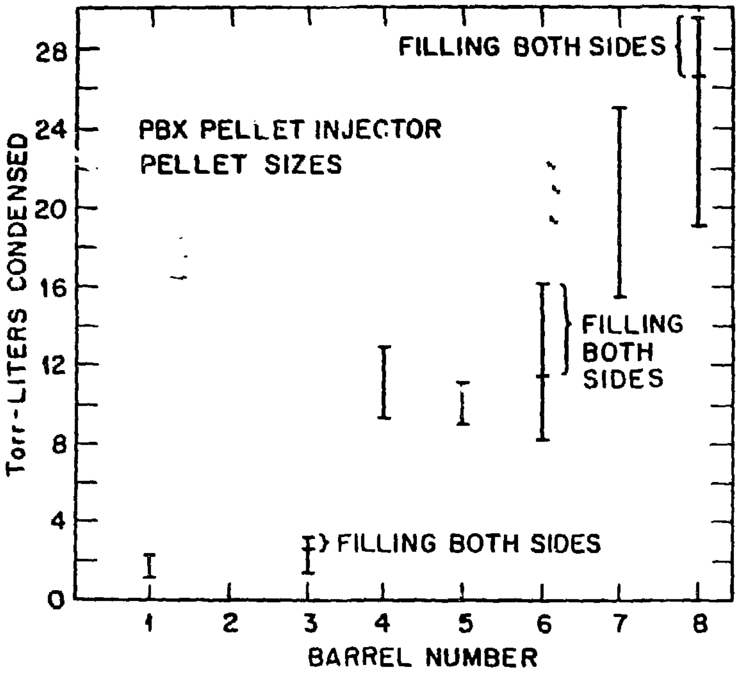


Fig. 7

ORNL-DWG 88-3351 FED



BARREL NUMBER	DIAMETER (in.)	WEB THICKNESS (in.)
1	0.041	0.033
2	0.041	0.027
3	0.041	0.039
4	0.085	0.055
5	0.085	0.066
6	0.085	0.078
7	0.116	0.100
8	0.116	0.118

Fig. 8

DISCLAIMER