PELLET INJECTOR RESEARCH AT ORNL*

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ABSTRACT

Advanced plasma fueling systems for magnetic confinement devices are under development at the Oak Ridge National Laboratory (ORNL). The general approach is that of producing and accelerating frozen hydrogen isotope pellets at speeds in the range 1-2 km/s and higher. Recently, ORNL provided pneumataic-based pellet fueling systems for two of the world's largest tokamak experiments, the Tokamak Fusion Test Reactor (TFTR) and the Joint European Torus (JET). A new versatile centrifuge type injector is being readied at ORNL for use on the Tore Supra tokamak. Also, a new simplified eight-shot injector design has been developed for use on the Princeton Beta Experiment (PBX) and the Advanced Toroidal Facility (ATF). In addition to these confinement physics related activities, ORNL is pursuing advanced technologies to achieve pellet velocities significantly in excess of 2 km/s and is carrying out a Tritium Proof-of-Principle (TPOP) experiment in which the fabrication and acceleration of tritium pellets have already been demonstrated. This paper describes these ongoing activities.

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1. INTRODUCTION

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The Oak Ridge National Laboratory (ORNL) as been developing pellet injectors for about ten years.[1-14] These devices produce frozen hydrogen isotope pellets and then accelerate the projectiles to speeds in the range of 1-2 km/s by either pneumatic (light gas gun) or mechanical (centrifugal force) techniques. A variety of designs have been developed, including single-shot (one pellet) guns,[2,4,7,10,14] multiple-shot (four and eight pellet) guns,[3,8,11] machine gun (single- and multiple-barrel) types,[5,6,9] and centrifugal accelerators.[13] These injectors have been used to inject hydrogen and deuterium pellets into plasmas on numerous tokamak experiments (see e.g., Refs. 15-20), resulting in improvements of plasma performance. Recently, ORNL provided pellet fueling systems for two of the largest tokamak experiments in the world, the Tokamak Fusion Test Reactor (TFTR) and the Joint European Torus (JET). The TFTR eight-shot pneumatic injector[8] was described in some detail at the last conference (1986).[21] The three-barrel repeating pneumatic injector[9] which is briefly described herein is the central part of a major collaboration between the United States and the European community on plasma fueling and transport physics in the high plasma density regime. The injector was installed on JET in 1987 and has been used in experiments during the last year. ORNL is in the process of completing a new version of the centrifuge pellet injector for installation and use on the Tore Supra tokamak. The new injector will be featured in a collaboration with the Commissariat á l'Energie Atomique (CEA). The objective of the ORNL-CEA collaboration in this area is to study long-pulse, reactor-relevant tokamak discharges with simultaneous plasma fueling and exhaust capabilities. These unique and versatile injectors are described below, along with other recent development activities.

2. PELLET INJECTORS FOR EXPERIMENTAL FUSION DEVICES

2.1 Three-Barrel Repeating Pneumatic Injector for JET

For plasma fueling applications on JET, a pellet injector fashioned after the prototype repeating pneumatic design[5,6] has been developed. The original repeating pneumatic injector was used in the initial pellet fueling experiments on TFTR[19] and was described at the last conference.[21] The gun-like device operates repetitively, using a cryogenic extruder to supply a continuous stream of hydrogen ice to the gun section where individual pellets are repetitively formed, chambered, and accelerated. The new, versatile device (Fig. 1) consists of three independent machine-gun-like mechanisms in a common vacuum enclosure and features three nominal pellet sizes (2.7-, 4.0-, and 6.0-mm-diam) and repetitive operation (5, 2.5, 1 Hz, respectively) for quasi-steady-state conditions (>10 s). Detailed descriptions of the injector design and operation has been described elsewhere. An example of recent pellet injector performance on JET is shown in Fig. 2 where the line density is plotted as a function of time for a 3-MA, 2-MW ICRF-heated discharge. In this example a 4-mm pellet was injected at 43 s, followed by an 8-s pulse of 2.7-mm pellets fired at a rate of 4 Hz. In this case, all 33 pellets entered the plasma. During a one-month-run period, a total of twenty-eight 4-mm and eighty-seven 2.7-mm pellets were fired into JET -- all but one successfully entered the vacuum chamber. The injector allows JET to achieve high plasma densities and push plasma operating parameters.

2.2 Centrifuge Injector for Tore Supra

For the application on the Tore Supra tokamak, a centrifuge-type injector design was chosen; the design is based on an earlier mechanical device[13] that provided the first time quasi-steady-state fueling on Doublet-III tokamak in 1984.[18] The centrifuge injector is a mechanical device that uses centrifugal forces to accelerate pellets constrained to move in a track on a high-speed rotating arbor.

Two inherent advantages of this technique are steady-state capability and high pellet feed rates. Thus, it can provide a flexible fuel source for long-pulse tokamaks. The injector performance goals for the new injector include (1) the capability of delivering 10-30 hydrogen or deuterium pellets per second for a 30-s pulse, (2) variable pellet size (1-10 torr-L/pellet), (3) pellet speeds in the range of 0.8-1.2 km/s ,and (4) pellet dispersion at the plasma surface within ± 30 mm. The injector system (Figs. 3 and 4) is primarily divided into three subsystems: (1) the vacuum containment "spin tank," (2) the pellet fabrication system or "Zamboni machine," and (3) the high-speed mechanical accelerator.

The vacuum containment is provided by a 2-m-diam dome-shaped "spin tank," which houses the accelerator and supports the pellet fabrication system. The "Zamboni Machine," replaces the conventional extruder assembly as the pellet fabrication mechanism. This device freezes a rim of solid hydrogen ice on a rotating disk which is cooled with liquid helium. On command, a quantity of pellets of variable sizes can be punched. The voids formed on the rim after punching a pellet sequence are replenished as the liquid helium-cooled disk rotates and gas fills through the injection calipers. The accelerator is a 1.5-m-diam snow-shoe shaped graphite composite hoop that is coupled to a high strength aluminum hub and is driven with an induction motor. A recessed area in the aluminum hub accepts the pellets from the "Zamboni" and guides them into a V-shape groove in the composite hoop where centrifugal forces accelerate the pellets to twice the peripheral speed of the rotor (tested at up to 127 Hz). The pellets are shot through a guide tube injection line to the plasma. After establishing satisfactory operation of the injector at ORNL, it will be delivered to Tore Supra for installation and checkout.

2.3 Simplified Eigh-Shot Pneumatic Pellet Injector Design

A simplified eight-shot pneumatic pellet injector design "has been developed at ORNL." Plasma fueling systems based on this design will be supplied to the Princeton Beta Experiment (PBX) and the Advanced Toroidal Facility (ATF). This injector design is based upon the so-called "pipe-gun" concept, in which deuterium and hydrogen pellets are formed by direct condensation in the gun barrel, a segment of which is held 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 tube with auxiliary heating collars. This injector (Fig. 5) features eight independent gun barrel assemblies mounted around the perimeter of a single cold block, each coupled to an ORNL-designed fast propellant valve.[12] Thus, the injector is capable of injecting up to eight pellets of sizes ranging from 1 to 3 mm in arbitrarily programmable firing sequences at speeds up to ≈1500 m/s. Construction and testing of one eight-shot unit has been completed at ORNL with delivery to PBX proceeding. The unit for ATF will be fabricated during the next year.

4. TRITIUM INJECTOR

The properties of tritium, especially its radioactive decay, are quite different from those of the other hydrogen isotopes. Decay heating, the production of ^{3}He and its effect on the physical properties of solid tritium, the need for tritium-compatible materials of construction, and use of double containment to prevent tritium release are all problems unique to tritium. Because of these differences, it is desirable to demonstrate the production and acceleration of tritium pellets.

A pipe gun has been developed for the Tritium Proof-of-Principle (TPOP) experiment (Fig. 8).[10,14] This injector is based on the pneumatic pipe-gun concept, in which pellets are formed *in situ* in the barrel and accelerated with high-pressure gas. This injector is ideal for tritium service because there are no moving parts inside the gun and because no excess tritium is required in the pellet production process. Removal of ^{3}He from tritium to prevent blocking of the cryopuming action by the noncondensible gas is accomplished with a cryogenic separator. The experiment has been installed and operated with tritium in the Tritium Systems Test Assembly (TSTA) at Los Alamos National Laboratory (LANL). The TPOP experiment is still in the preliminary stages of operation. Figure 9 shows velocities obtained for both deuterium and tritium pellets. These data indicate that velocities of 1500 m/s should be readily obtainable for tritium pellets using present technology.

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Fig. 1 Three-barrel repeating pneumatic pellet injector for JET.

Fig. 2 Density evolution for thirty-three pellets injected into a 3-MA, 2-MW ICRF-heated JET discharge (one 4-mm pellet at 43s followed by thirty-two 2.7-mm pellets fired at a rate of 4 Hz).

Fig. 3 Components for Tore Supra centrifuge pellet injector.

Fig. 4 Details of the pellet fabrication device and high-speed rotating arbor for the Tore Supra application.

Fig. 5 Inside view of PBX eight-shot pellet injector showing propellant valves, cryogenic blocks, and gun barrels.

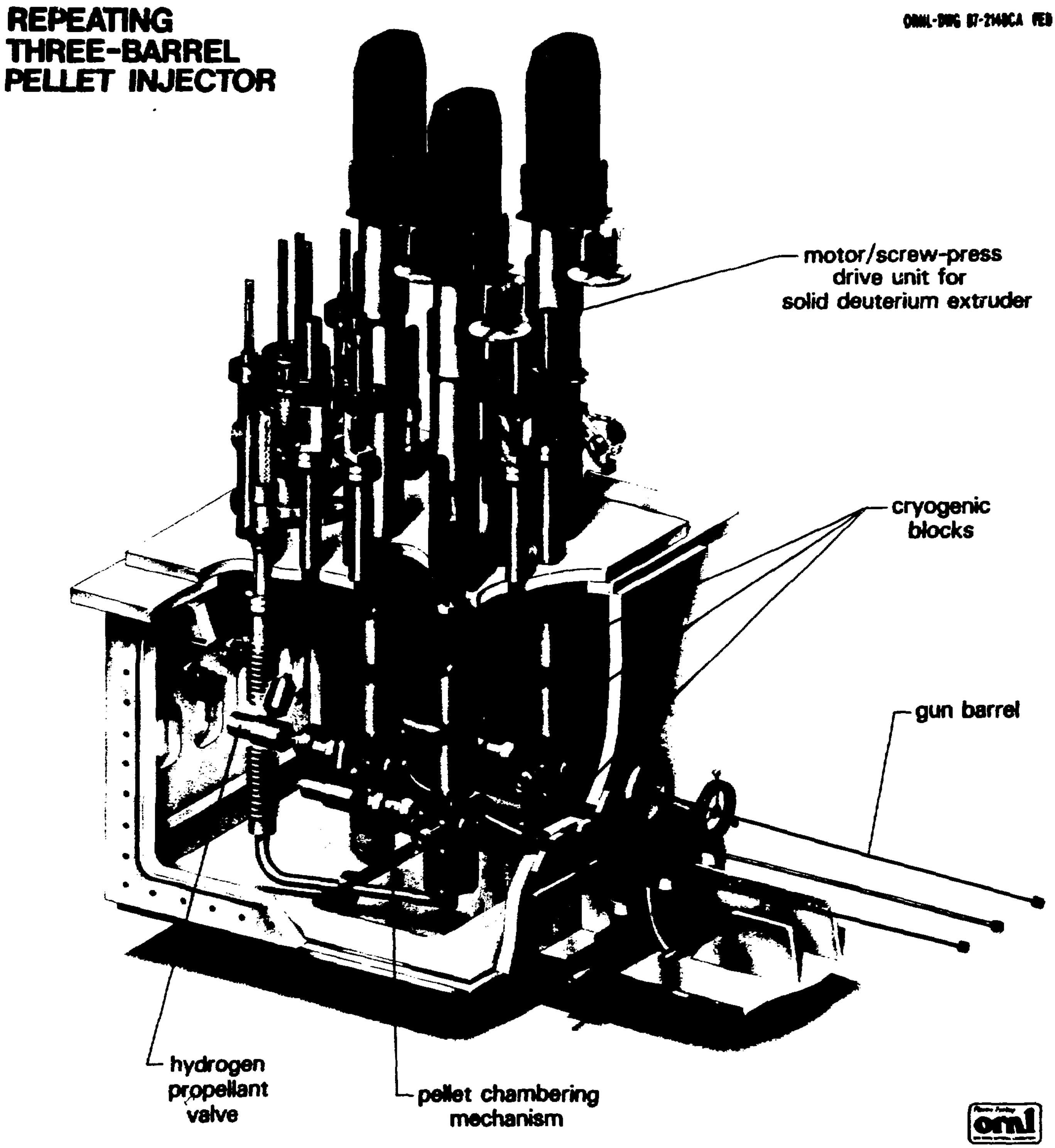
Fig. 6 Experimental setup of electron-beam rocket pellet accelerator.

Fig. 7 Two-stage light gas gun.

Fig. 8 Equipment for TPOP experiment ("pipe gun" pellet injector is inside glove box).

Fig. 9 Pellet velocity data from TPOP experiment.

Fig. 1


REPEATING
THREE-BARREL
PELLET INJECTOR
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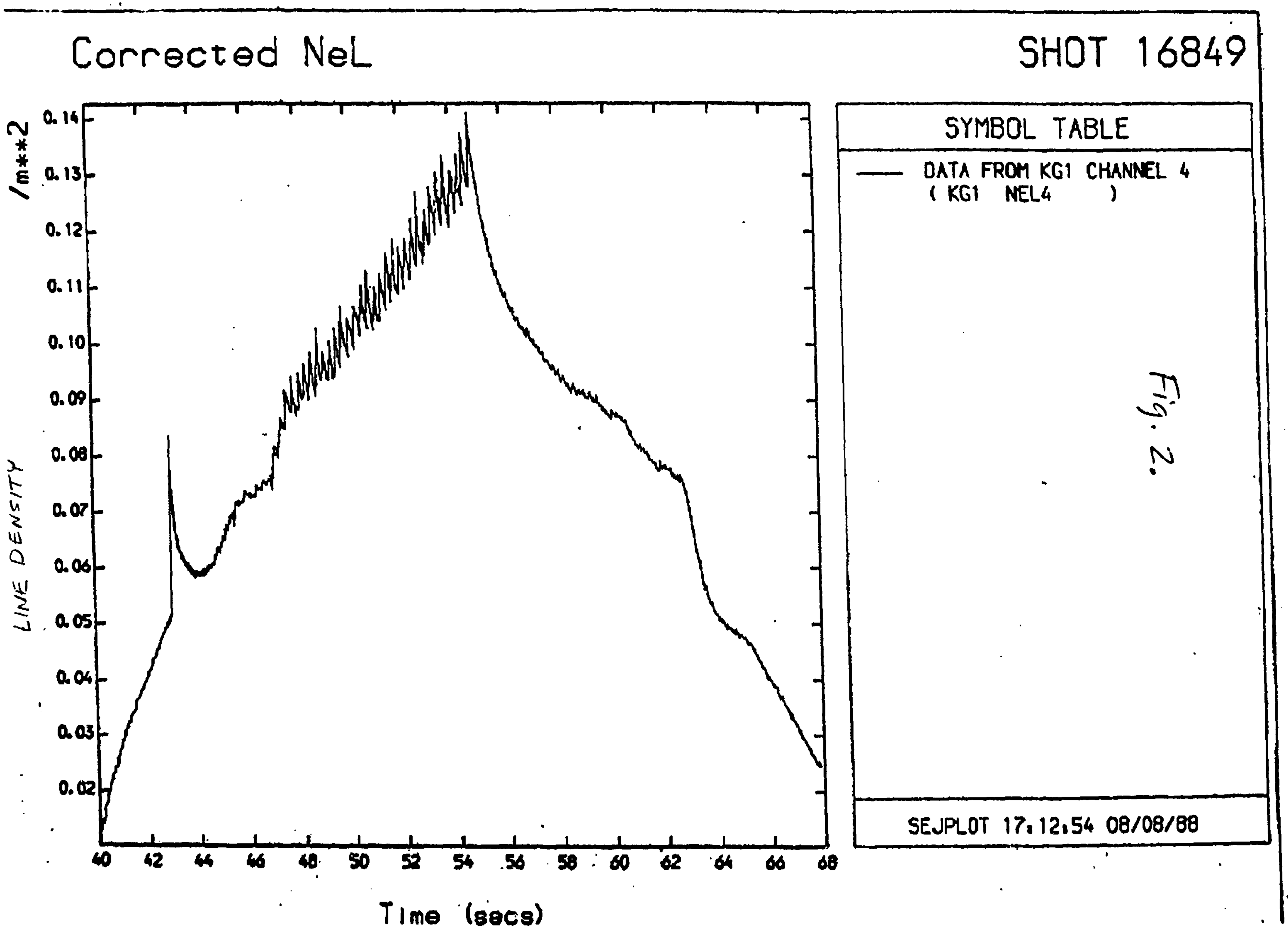
motor/screw-press
drive unit for
solid deuterium extruder
cryogenic
blocks
gun barrel
hydrogen
propellant
valve
pellet chambering
mechanism
ornl



Corrected NeL
SHOT 16849
/m**2
LINE DENSITY
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
40
42
44
46
48
50
52
54
56
58
60
62
64
66
68
Time (secs)
SYMBOL TABLE
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Fig. 2.

Fig. 3.

88-3377

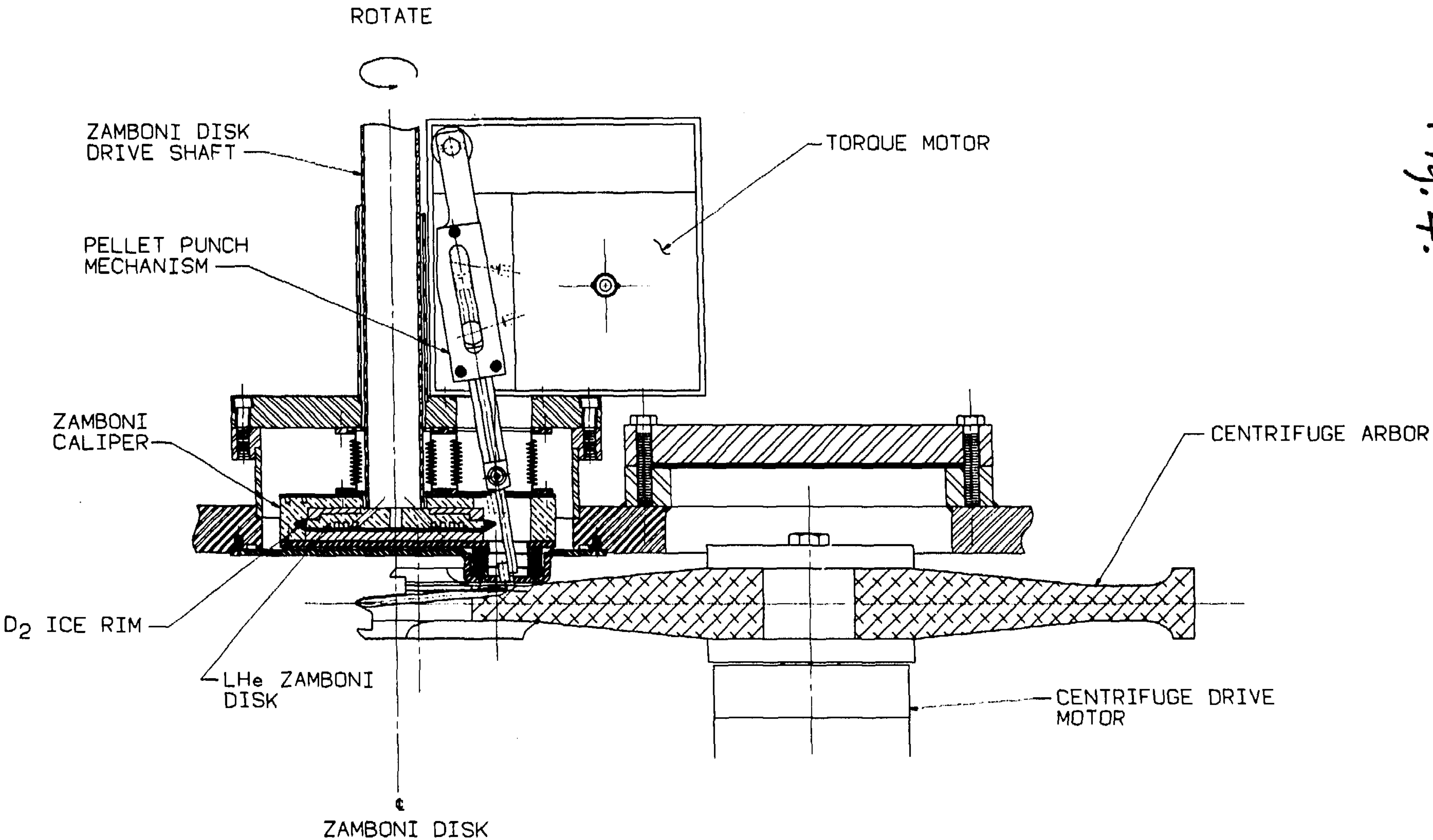
ROTATE
ZAMBONI DISK
DRIVE SHAFT
TORQUE MOTOR
PELLET PUNCH
MECHANISM
ZAMBONI
CALIPER
CENTRIFUGE ARBOR
D2 ICE RIM
LHe ZAMBONI
DISK
CENTRIFUGE DRIVE
MOTOR
ZAMBONI DISK

Fig. 4.

Fig. 5

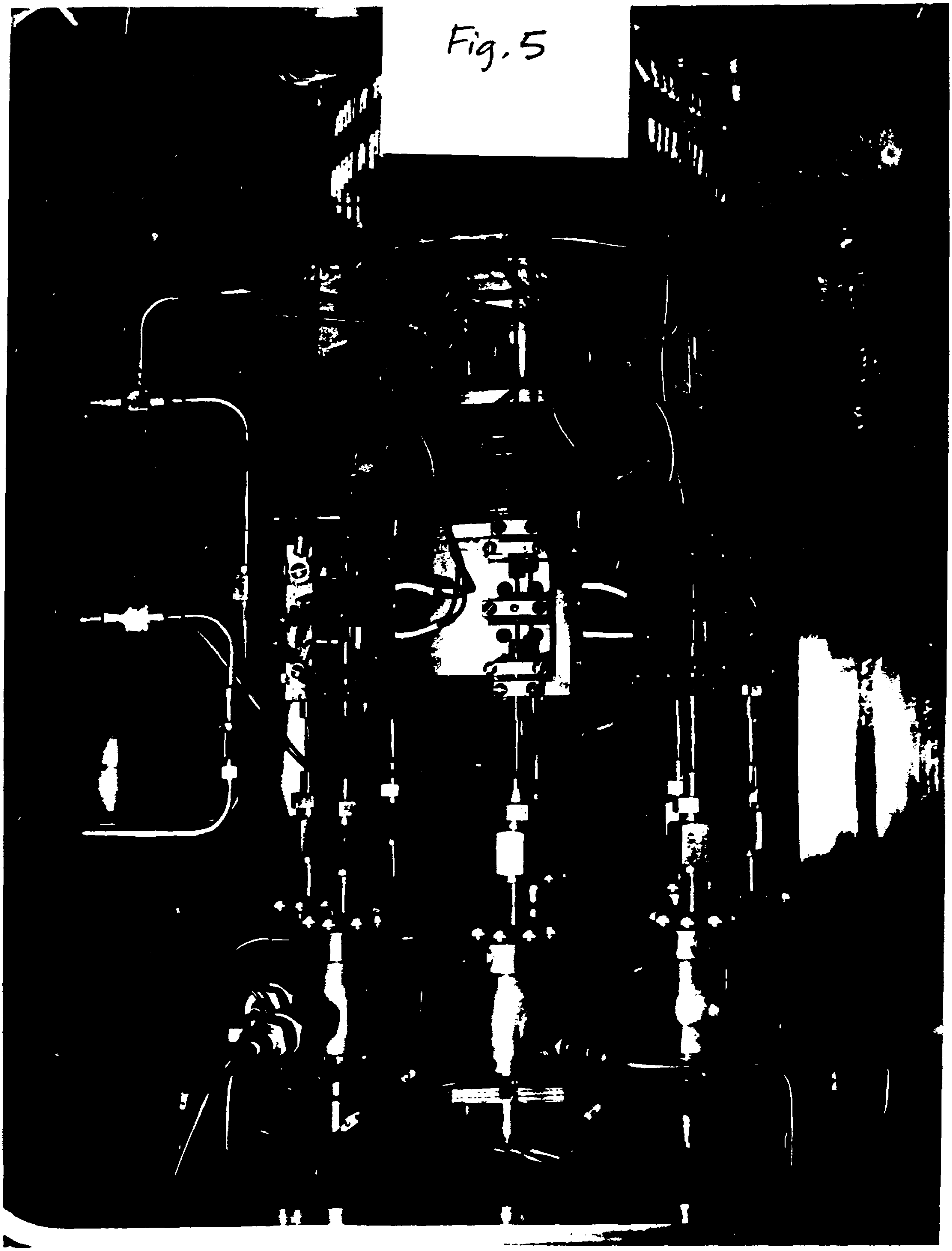

FIGURE A SKETCH OF EXPERIMENTAL SETUP OF A ... ROCKET PELLET

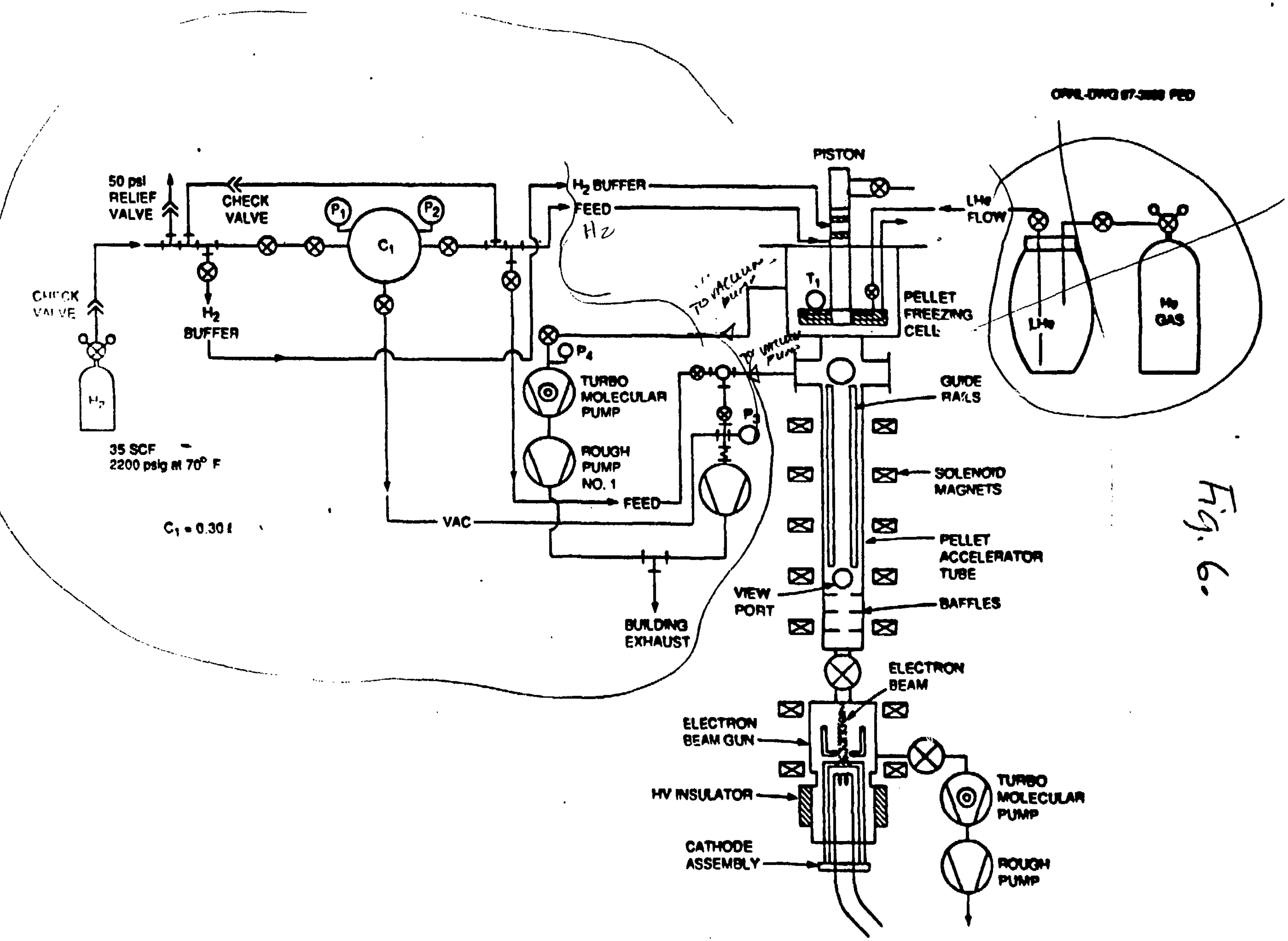

Fig. 6.

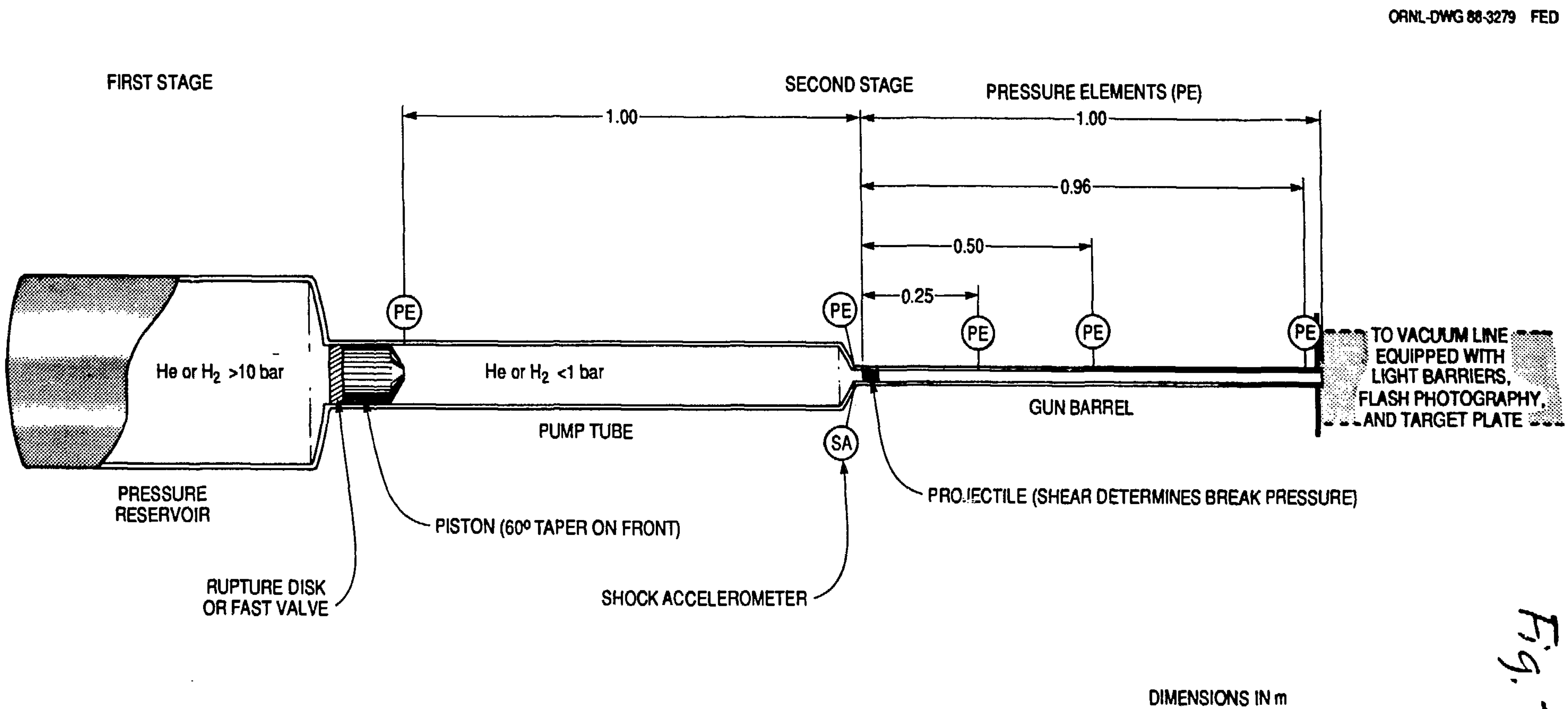
ORNL-DWG 88-3279 FED
FIRST STAGE
SECOND STAGE
PRESSURE ELEMENTS (PE)
1.00
1.00
0.96
0.50
0.25
PE
PE
PE
PE
PE
He or H2 >10 bar
He or H2 <1 bar
TO VACUUM LINE EQUIPPED WITH LIGHT BARRIERS, FLASH PHOTOGRAPHY, AND TARGET PLATE
GUN BARREL
PUMP TUBE
SA
PRESSURE RESERVOIR
PROJECTILE (SHEAR DETERMINES BREAK PRESSURE)
PISTON (60º TAPER ON FRONT)
RUPTURE DISK OR FAST VALVE
SHOCK ACCELEROMETER
DIMENSIONS IN m

Fig. 7.

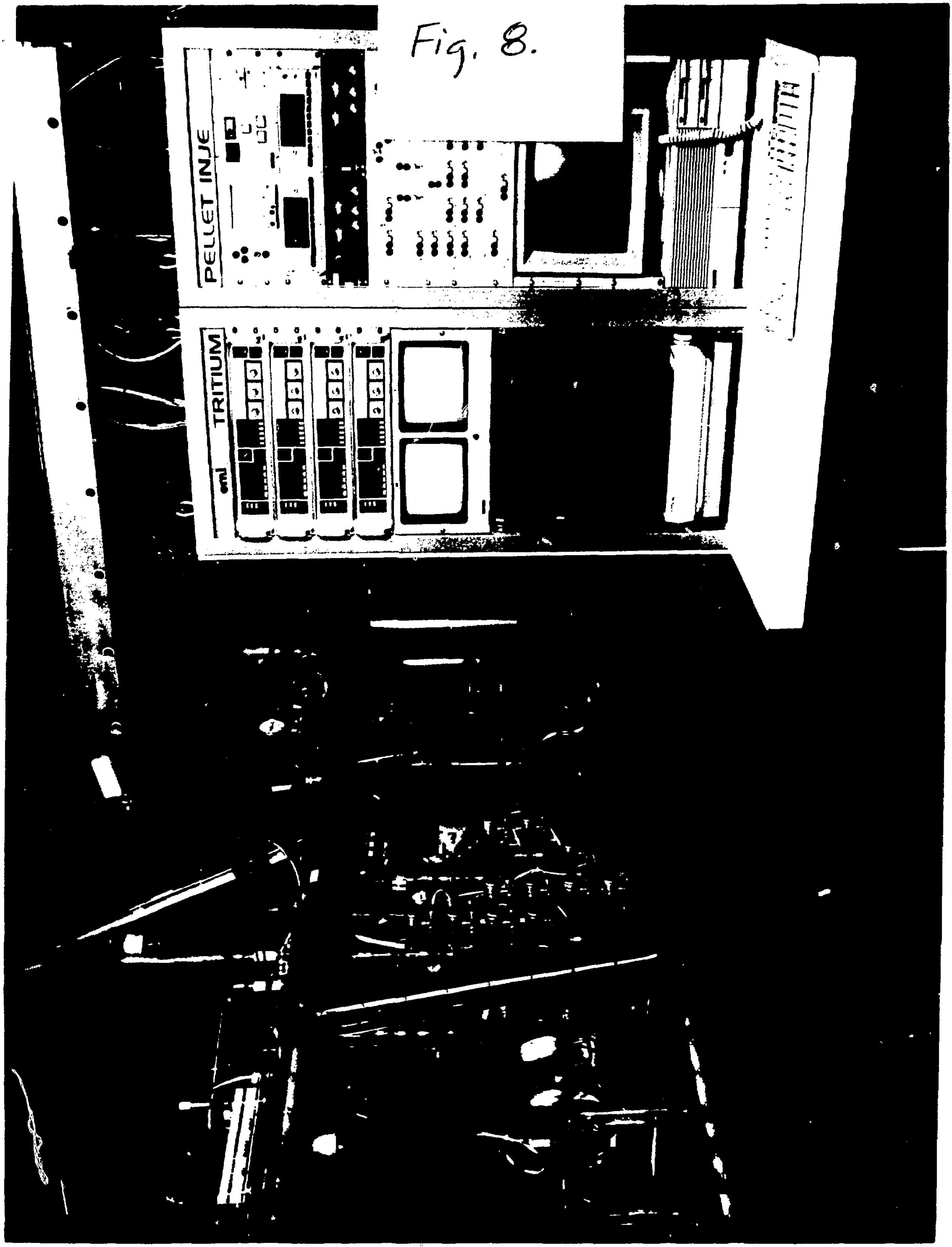

Fig. 8.

2853-87

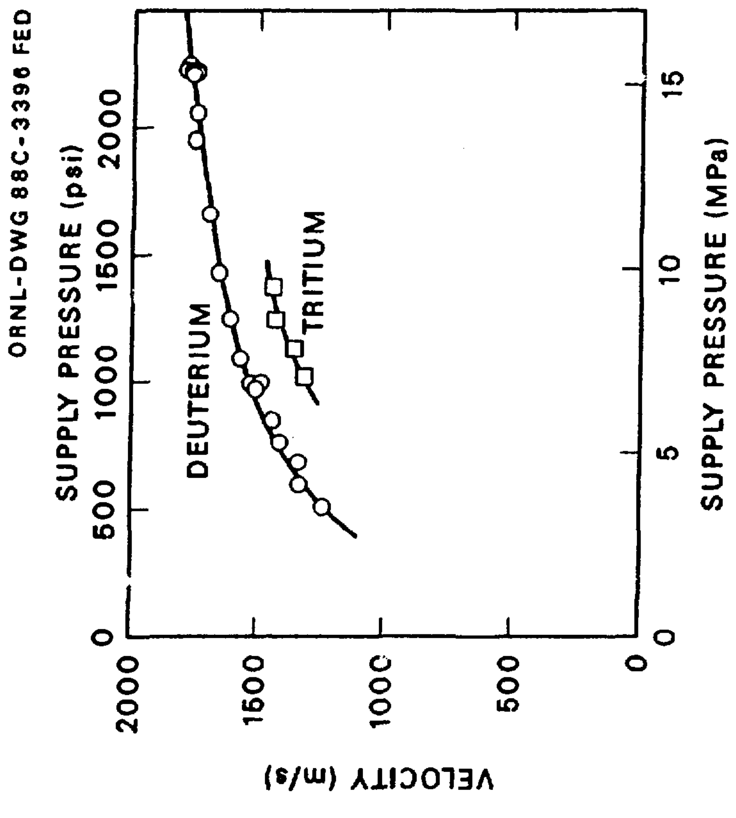
ORNL-DWG 88C-3396 FED
SUPPLY PRESSURE (psi)
0
500
1000
1500
2000
DEUTERIUM
TRITIUM
SUPPLY PRESSURE (MPa)
0
5
10
15
VELOCITY (m/s)
2000
1500
1000
500
0

Fig. 9.