CONF-8510266--3

OPERATION OF THE REPEATING PNEUMATIC INJECTOR ON TFTR AND DESIGN OF AN 8-SHOT DEUTERIUM PELLET INJECTOR

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INTERNATIONAL PELLET FUELING WORKSHOP

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OPERATION OF THE REPEATING PNEUMATIC INJECTOR ON TFTR AND DESIGN OF AN 8-SHOT DEUTERIUM PELLET INJECTOR

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The repeating pneumatic hydrogen pellet injector, which was developed at the Oak Ridge National Laboratory (ORNL), has been installed and operated on the Tokamak Fusion Test Reactor (TFTR). The injector combines high-speed extruder and pneumatic acceleration technologies to propel frozen hydrogen isotope pellets repetitively at high speeds. The pellets are transported to the plasma in an injection line that also serves to minimize the gas loading on the torus; the injection line incorporates a fast shutter valve and two stages of guide tubes with intermediate vacuum pumping stations. A remote, stand-alone control and data acquisition system is used for injector and vacuum system operation. In early pellet fueling experiments on TFTR, the injector has been used to deliver deuterium pellets at speeds ranging from 1.0 to 1.5 km/s into plasma discharges. First, single large (nominal 4-mm-diam) pellets provided high densities in TFTR (1.8×10^{14} cm^{-3} on axis); after conversion to smaller (nominal 2.7-mm-diam) pellets, up to five pellets were injected at 0.25-s intervals into a plasma discharge, giving a line-averaged density of 1×10^{14} cm^{-3}. Operating characteristics and performance of the injector in initial tests on TFTR are presented.

The repeating pneumatic injector is a device from the ORNL development program. More recently, an 8-shot deuterium pellet injector has been designed specifically for the TFTR application and is scheduled to replace the repeating injector next year. The new device will combine a cryogenic extruder and a cold wheel rotary mechanism to form and chamber eight pellets in a batch operation; the eight pellets can then be delivered in any time sequence. Another unique feature of the device is the variable pellet size with three pellets each of 3.0 and 3.5 mm diam and two each of 4.0 mm diam. The experience and technology that have been developed on previous pneumatic injectors at ORNL have been utilized in the design of this latest injector system.

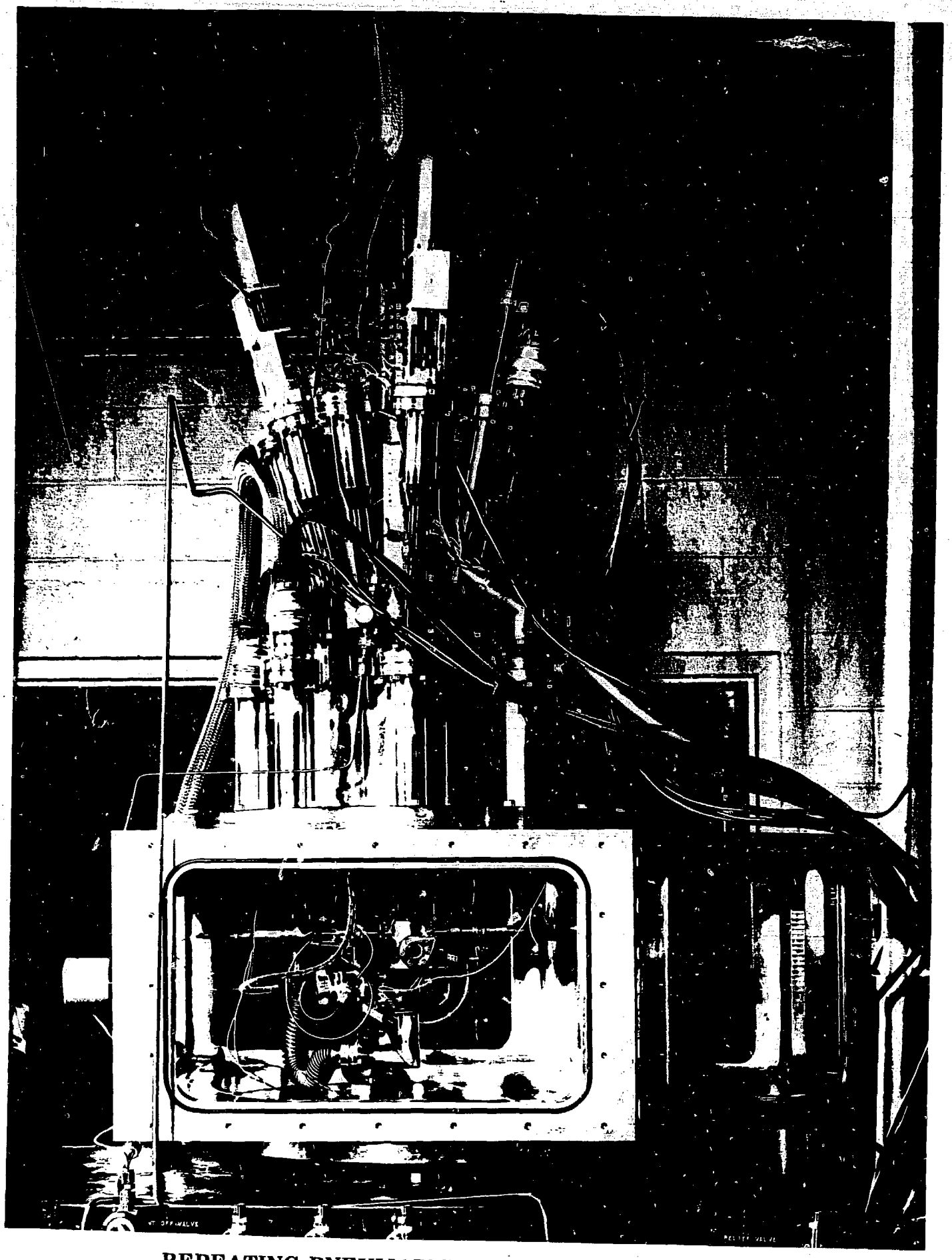
* Research sponsored by the Office of Fusion Energy, U.S. Department of Energy, under Contract No. DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

Two Pneumatic Pellet Injectors For Plasma Fueling Applications On TFTR

- Repeating Pneumatic Injector (RPI), a device from ORNL development program, has been used in initial fueling experiments on TFTR.
  - fixed pellet size; 4 mm diam available for first experiments (changeable with some difficulty, e. g., conversion to 2.7 mm diam for second series of experiments)
  - pellet speeds up to 1.6 km/s with deuterium pellets (1.9 km/s with hydrogen pellets)
  - repetition rates up to $4-6\ s^{-1}$ (2 – 4 s duration)
- 8–Shot Deuterium Pellet Injector (DPI) was designed specifically for TFTR and will replace RPI next year
  - variable pellet size (3.0, 3.5, and 4.0 mm diam)
  - speed capability similar to RPI
  - deliver eight pellets in any time sequence

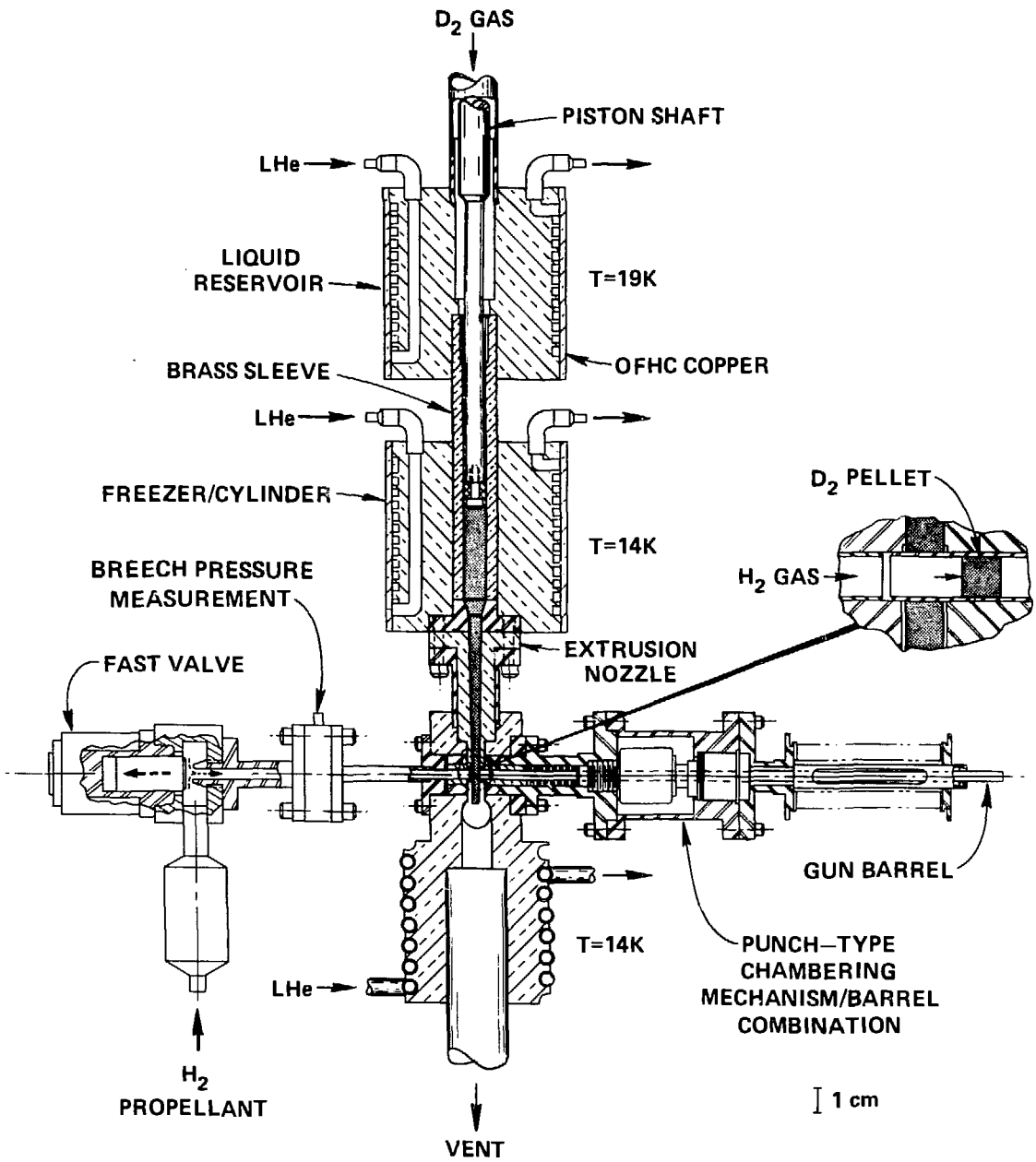
Repeating Pneumatic Injector

- Description of Equipment
  - Cryogenic extruder and gun assembly
  - Installation on TFTR including pellet injection line
  - Control and Data Acquisition System
- Injector Performance On TFTR
- Plasma Density Results



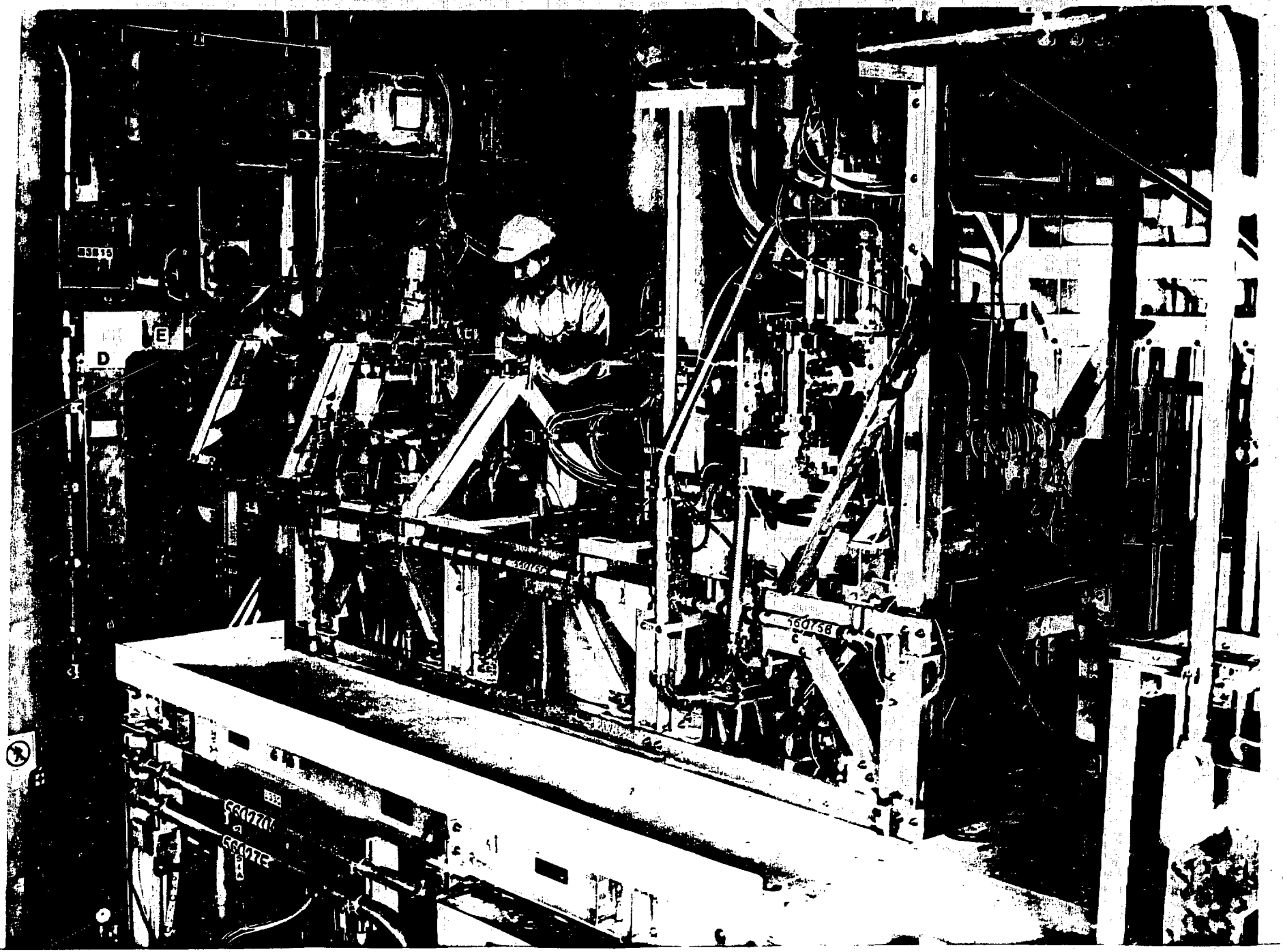
REPEATING PNEUMATIC INJECTOR (RPI)

ORNL–DWG 85–3206 FED



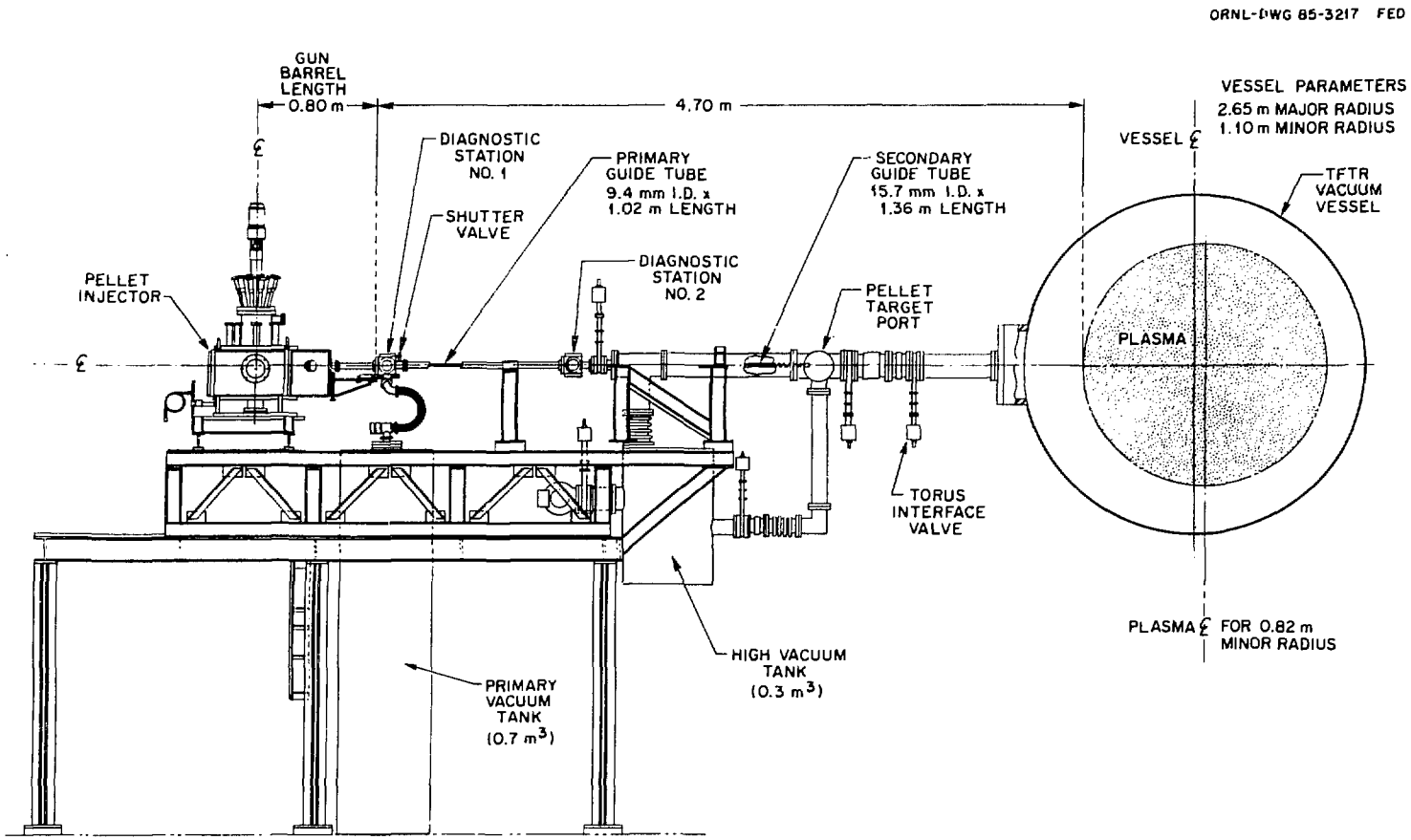
SCHEMATIC OF CRYOGENIC EXTRUDER AND GUN ASSEMBLY FOR RPI

10/30-11/3/85-SKC(VG-4)



PHOTOGRAPH OF RPI INSTALLATION ON TFTR

10/30-11/3/85-SKC(VG-5)



SCHEMATIC OF RPI INSTALLATION ON TFTR

Stand-Alone Control and Data Acquisition System Is Used for Injector and Vacuum System Operation On TFTR

- Model 2/30 Allen-Bradley Programmable Logic Controller (PLC) performs all of the control functions and is interfaced via CAMAC to a VAX 11/730 mini-computer for remote operation.

- Local operation is provided by an intelligent panel system with a keypad and push-button module programmed from the PLC.

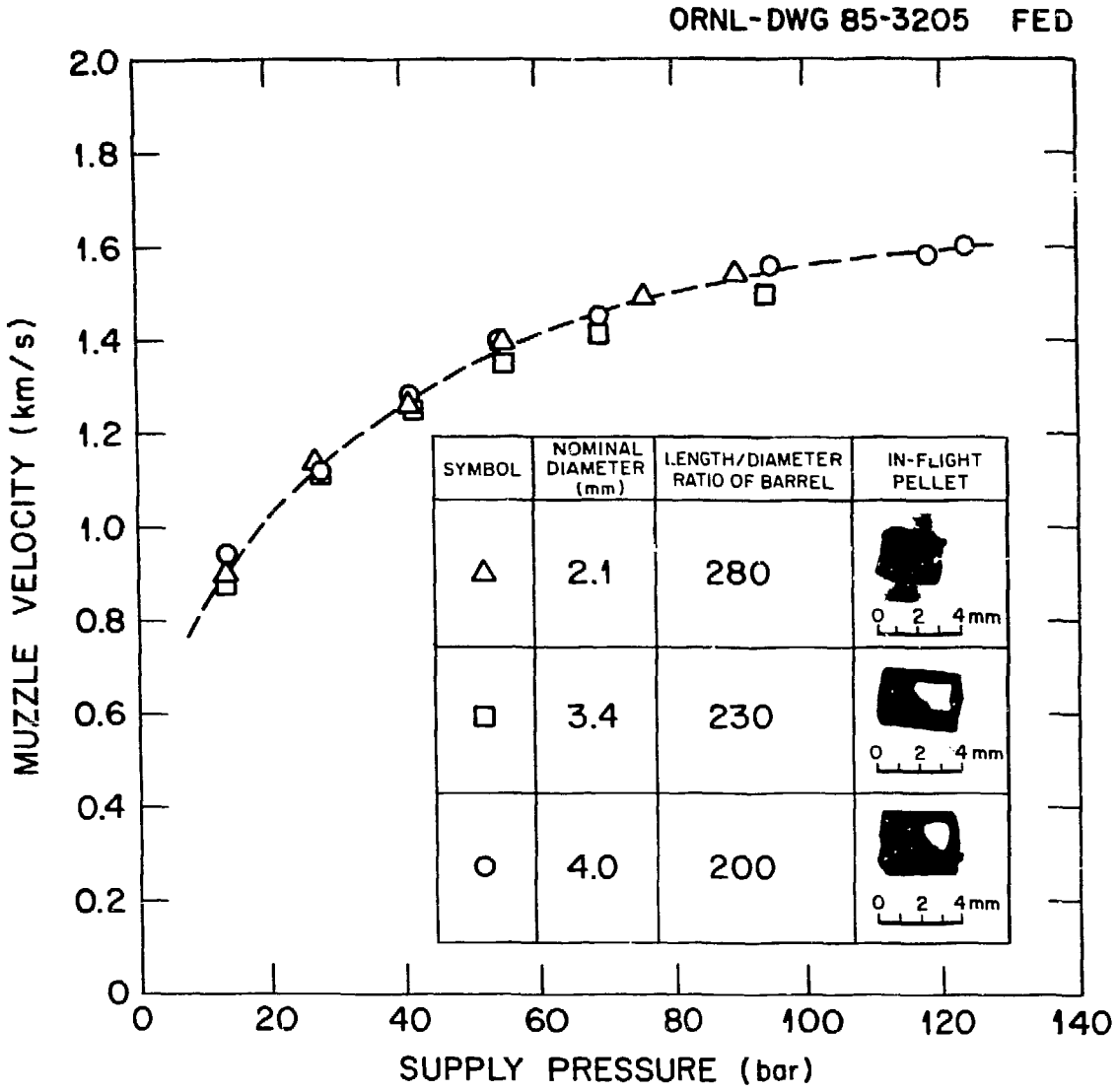
- VAX has a CAMAC serial highway interface which is used for:
  - Color graphics status and mimic displays
  - Data acquisition from transient recorders
  - Communications link with the PLC and fire control sequencer
  - Interconnection to the timing and control systems of TFTR

- System is operated remotely through a combination of track-ball and keyboard commands

- Data archives are maintained for both transient data from pellet shots and trend data acquired from the PLC during operation.

Injector Performance On TFTR

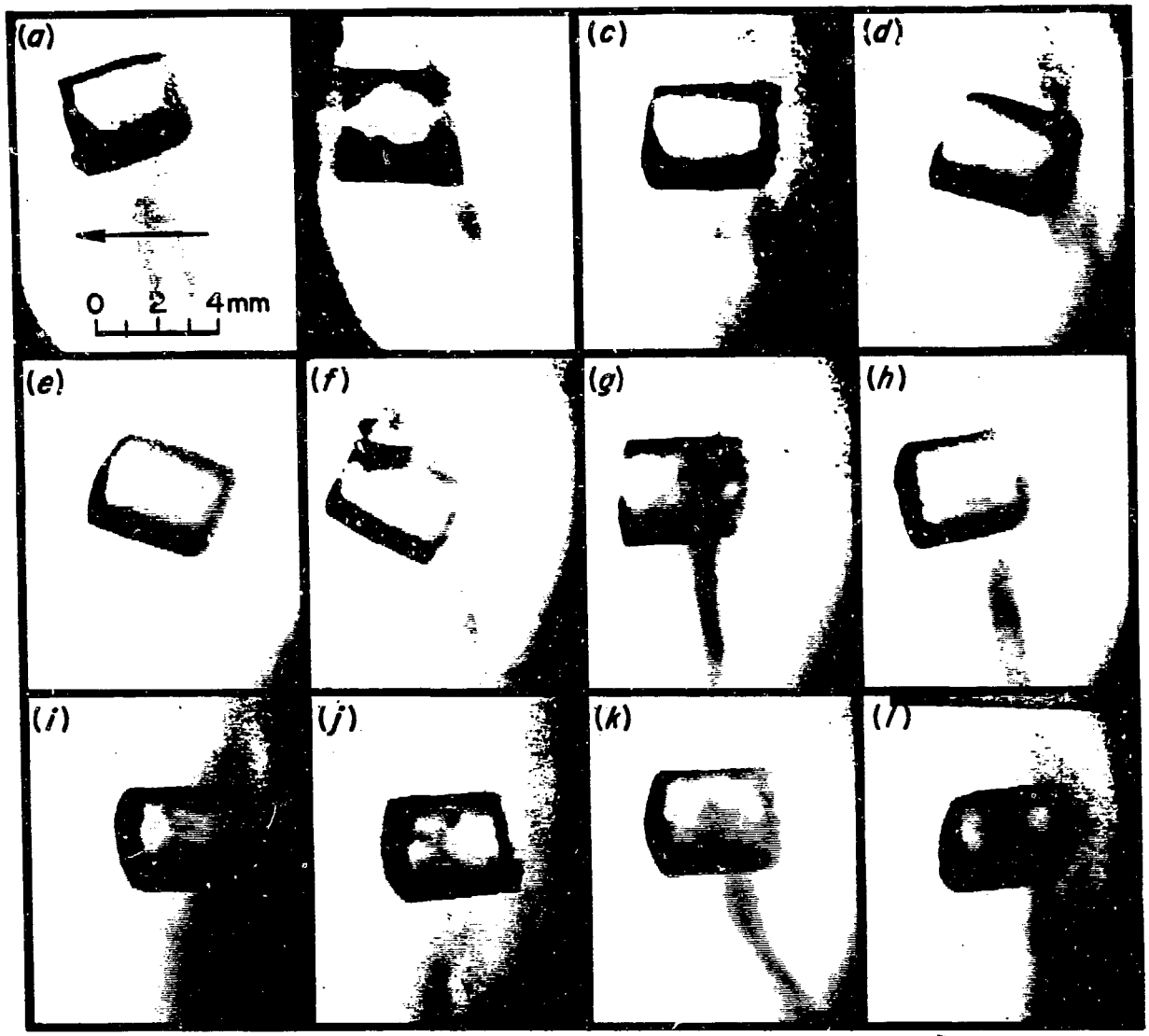
- Pellet Parameters
  - Pellet Sizes: Nominal 4.0 and 2.7 mm diam
  - Pellet Speeds: 1.0 – 1.5 km/s
  - Repetition Rate: up to 4 s^{-1} for 1.25 s burst
- Pellet Injection Line
  - Negligible angular dispersion in pellet trajectory
  - Propellant gas injected into tokamak limited to 0.04 torr · L per pellet



PELLET VELOCITY DATA FOR DEUTERIUM PELLETS IN LABORATORY OPERATION OF RPI (SHADOWGRAPHS OF IN-FLIGHT PELLETS ARE SHOWN)

10/30-11/3/85-SKC(VG-9)

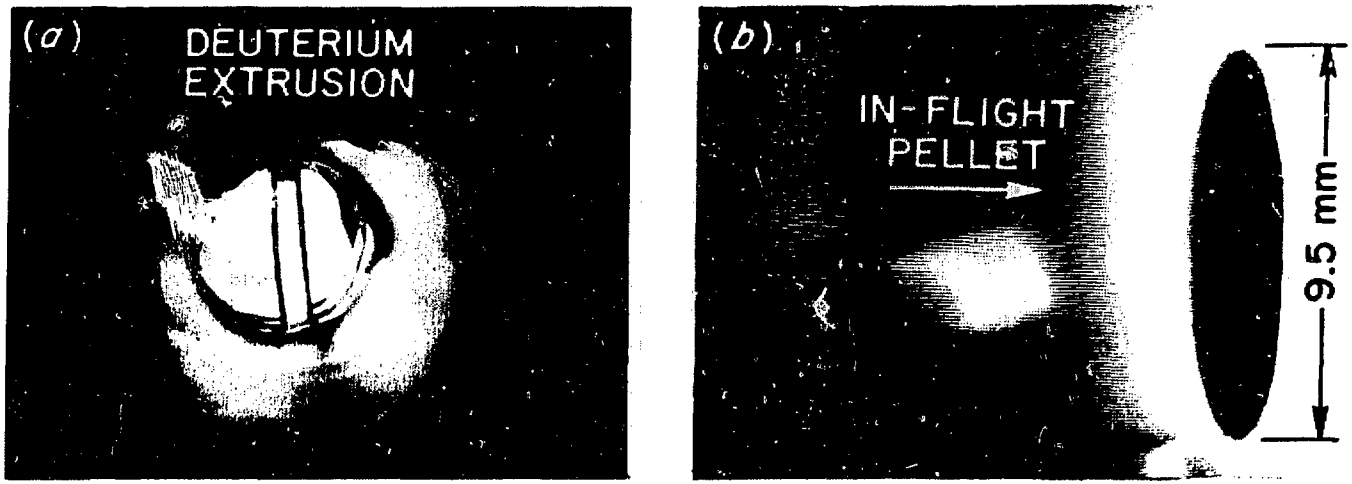
ORNL-PHOTO 0002-85 FED



SHADOWGRAPHS OF 12 CONSECUTIVE PELLETS TAKEN DURING REPETITIVE OPERATION OF RPI AT A FIRING RATE OF 6 s-1 FOR 2-s BURST (LABORATORY OPERATION WITH NOMINAL 4.0-mm-DIAMETER HYDROGEN PELLETS; 80-cm GUN BARREL; 83-BAR PROPELLANT SUPPLY PRESSURE; AND ≈ 1500-m/s MUZZLE VELOCITY)

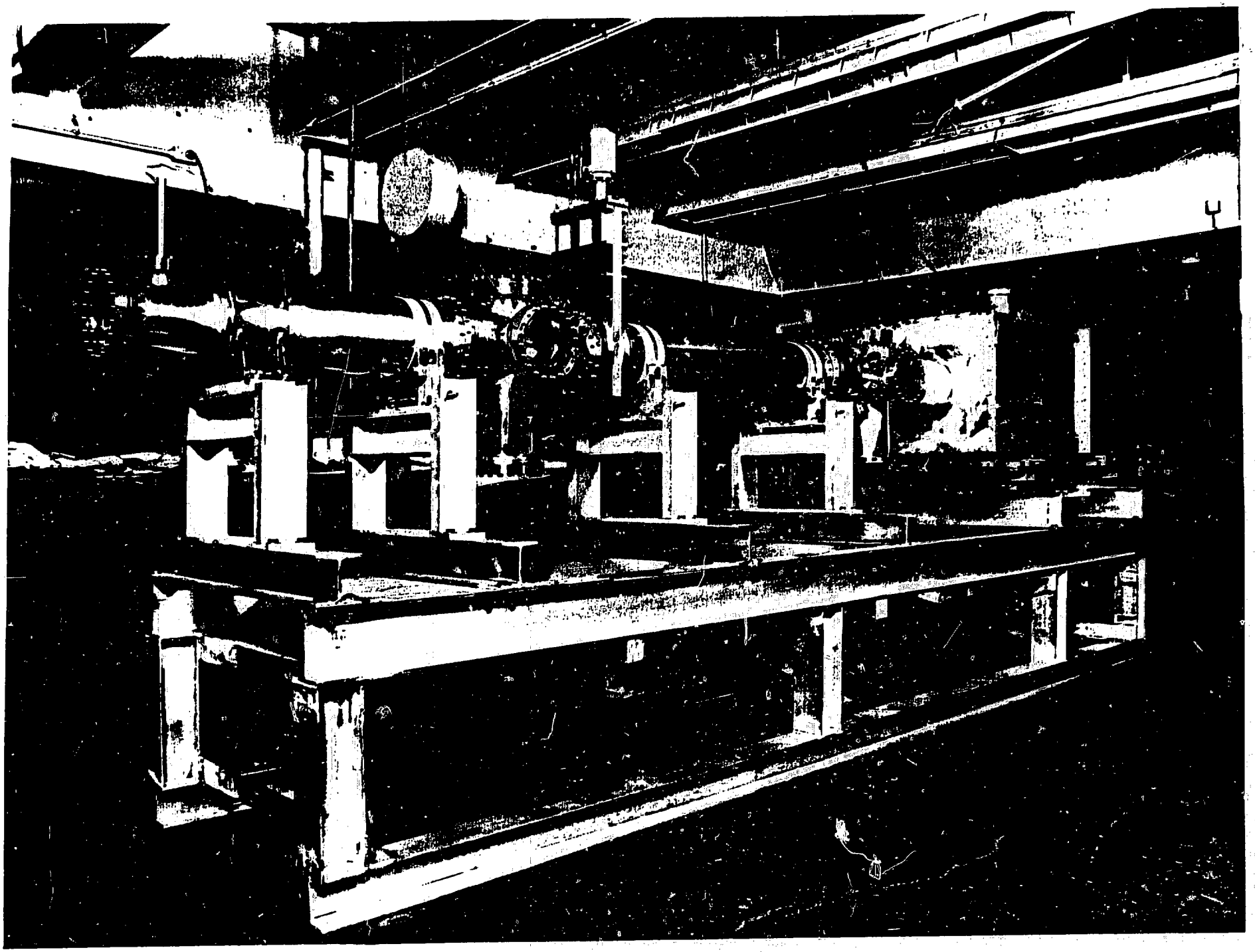
10/30-11/3/85-SKC(VG-10)

ORNL-PHOTO 0009-85 FED



**VISUAL DISPLAYS IN THE TFTR CONTROL ROOM:
(a) SOLID DEUTERIUM EXTRUSION AS VIEWED BELOW RPI GUN MECHANISM AND (b) IN-FLIGHT DEUTERIUM PELLET (SPEED ≈ 1300 m/s).**

10/30-11/3/85-SKC(VG-11)



PELLET INJECTION LINE FOR 8-SHOT DPI

10/30-11/3/85-SKC(V6-22)

Physical pellet parameters

	Pellet size	
	Large	Small
Nominal size[a]		
Diameter, mm	4.0	2.7
Length, mm	3.4	2.5
Measured size[b]		
Diameter, mm	3.6	2.5
Length, mm	4.0	3.0
Pellet load[c]		
Volume, mm^3	42.7	14.3
Weight, mg	8.5	2.9
PV, torr·L	36	12
$N(D^0)$	2.5×10^{21}	8.6×10^{20}

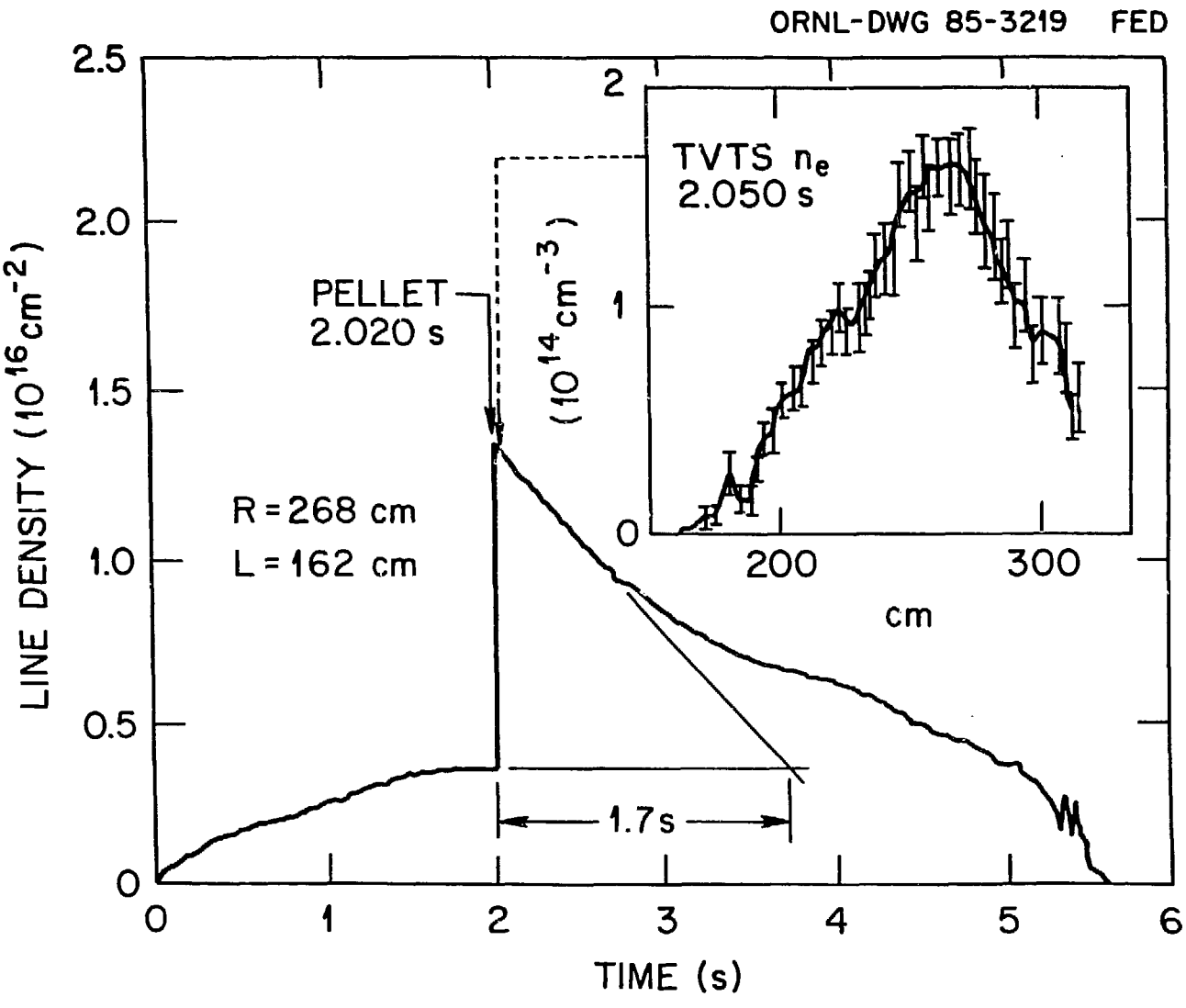
[a]Determined by gun barrel bore (diameter) and thickness of extrusion (length).

[b]Determined from photographs of in-flight pellets (represents average size).

[c]Based on nominal sizes; using measured sizes, pellet load is calculated to be within 5% of listed values. The density was taken as 0.2 g/cm^3 for solid deuterium.

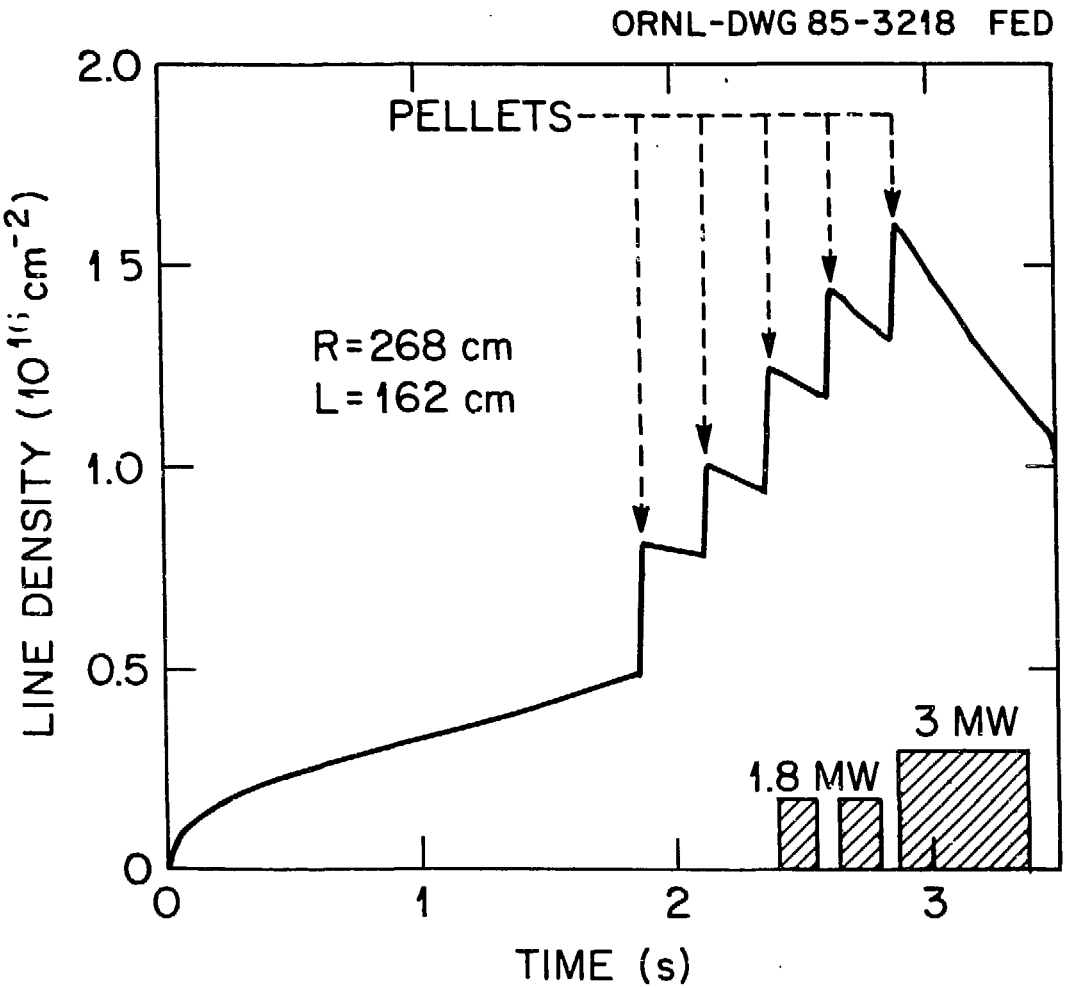
Plasma Density Results

- Single 4 – mm deuterium pellets were injected into 1.4–MA ohmic plasmas
  - line-averaged density = 8.1×10^{13} cm^{-3}
  - near triangular shape for density profile
  - central density = $1.6–1.8 \times 10^{14}$ cm^{-3}
- After conversion to 2.7–mm pellets, up to five pellets were injected into a plasma on a single machine pulse with neutral beam operation.
  - injected at 0.25 -s intervals into a staggered beam
  - line-averaged density = 1×10^{14} cm^{-3}



DENSITY EVOLUTION AND PROFILE SHAPE FOR SINGLE 4-mm DEUTERIUM PELLET INJECTED INTO 1.4-MA TFTR OHMIC PLASMA

10/30-11/3/85-SKC(VG-14



DENSITY EVOLUTION FOR FIVE 2.7-mm DEUTERIUM PELLETS INJECTED INTO 2.2 MA TFTR PLASMA (STAGGERED NEUTRAL BEAM OPERATION IS ILLUSTRATED; PELLETS AT 1.880, 2.130, 2.380, 2.630, AND 2.880 s INTO DISCHARGE WITH BEAMS FROM 2.400 TO 2.550 s, 2.635 TO 2.805 s, AND 2.885 TO 3.385 s).

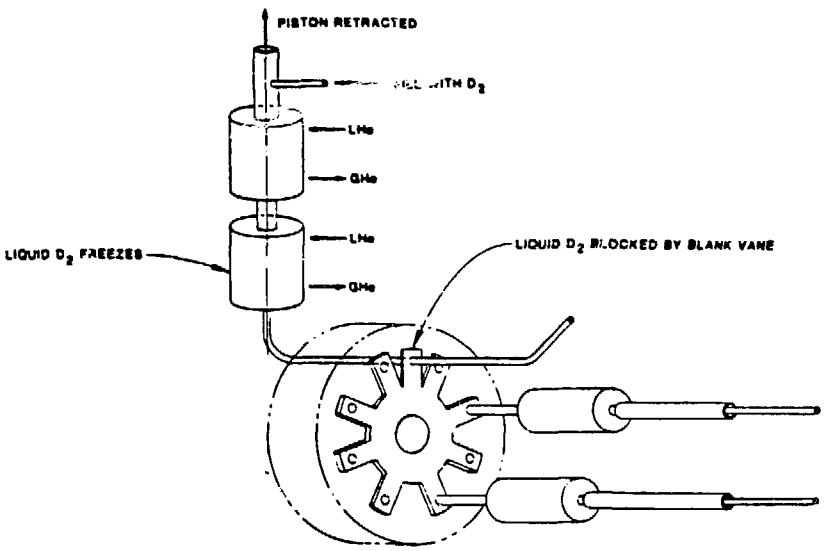
8-Shot Deuterium Pellet Injector (DPI)

- Number of Pellets = 8
- Pellet Sizes
  - 3.0 mm diam × 3.5 mm long (3 ea)
  - 3.5 mm diam × 3.5 mm long (3 ea)
  - 4.0 mm diam × 3.5 mm long (2 ea)
- Pellet Speed $\approx$ 1.6 km/s maximum
  (Propellant Pressure = 1500 psig maximum)
- Eight pellets can be fired in any time sequence

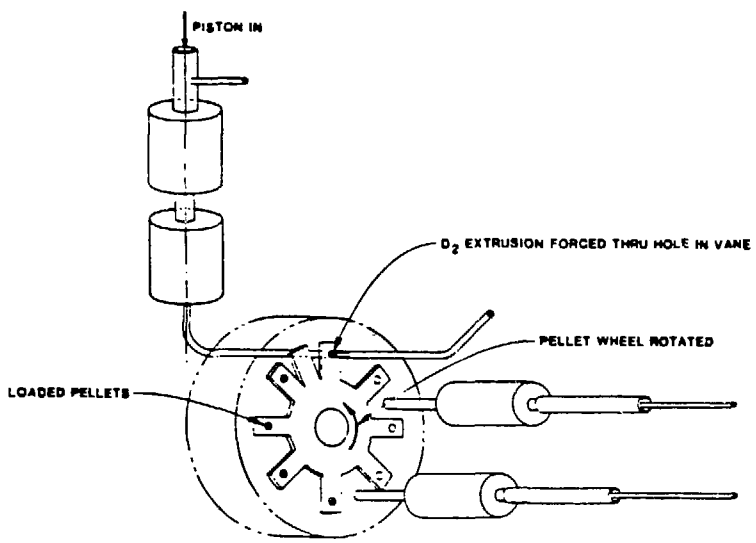
DPI Uses Technology Developed For Previous Injectors At ORNL

- Cryogenic Extruder (RPI and Centrifuge Devices)
- Propellant Valves (RPI)
- Shutter Valves on Injection Line for Limiting Gas Throughput (RPI)
- Pellet Injector line (RPI and 4–Shot Injectors)
- Cold Wheel Rotary Mechanism (4–Shot Injectors)

This device is the first at ORNL that combines an extruder and a rotating disk; also the guide tubes have a 0.625° taper.

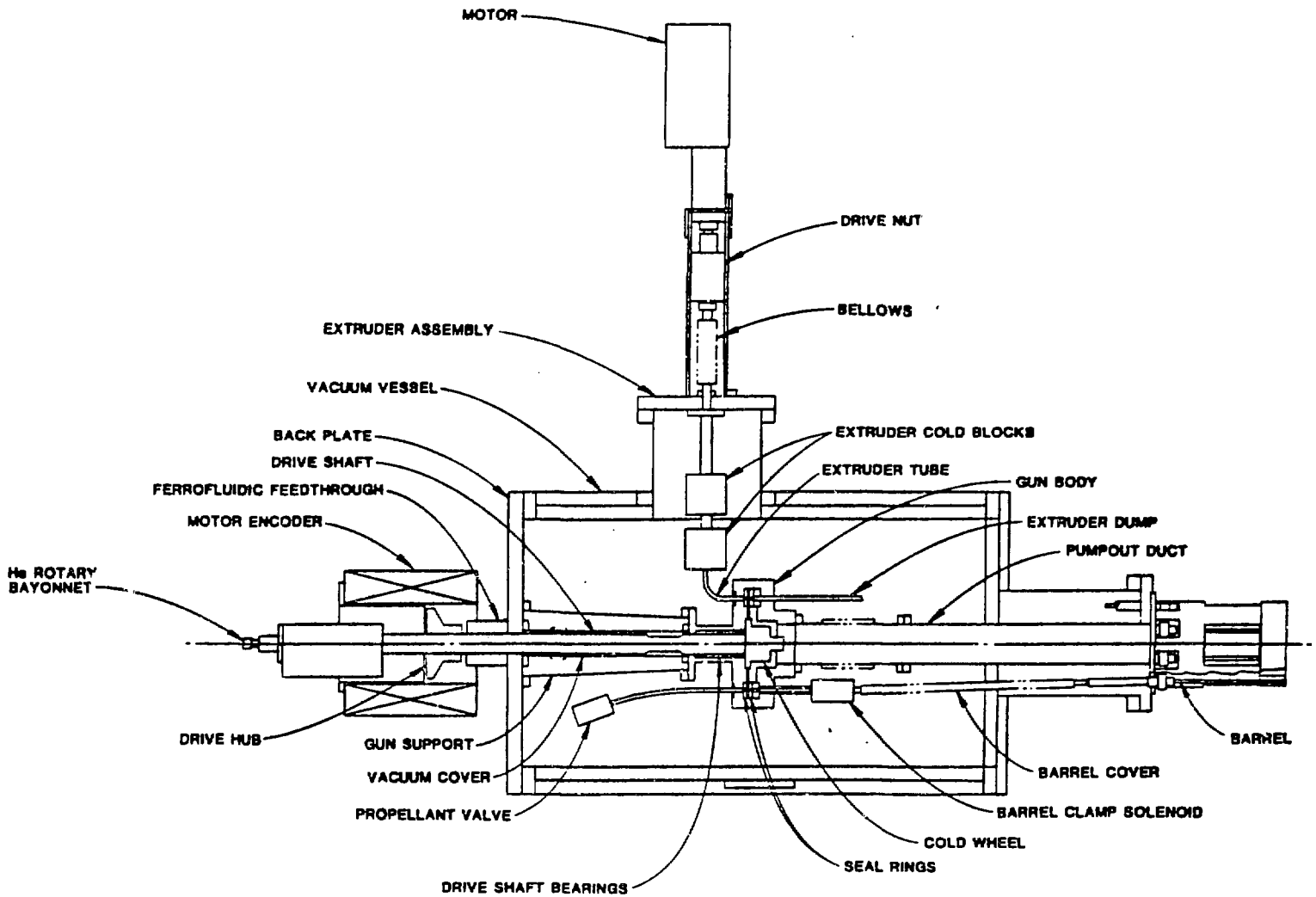


EXTRUSION FORMATION



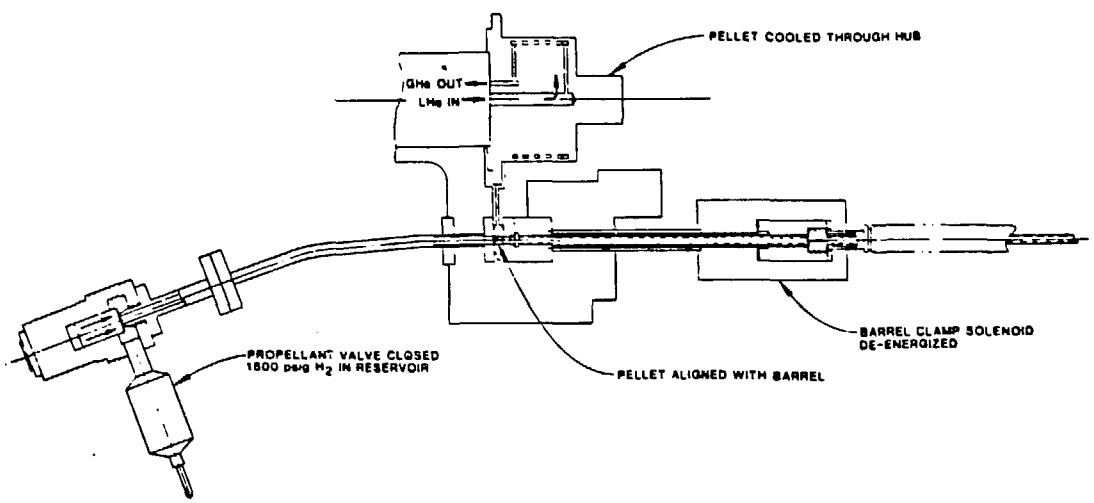
PELLET LOADING

SCHEMATIC OF CRYOGENIC EXTRUDER AND PELLET LOADING MECHANISM FOR DPI

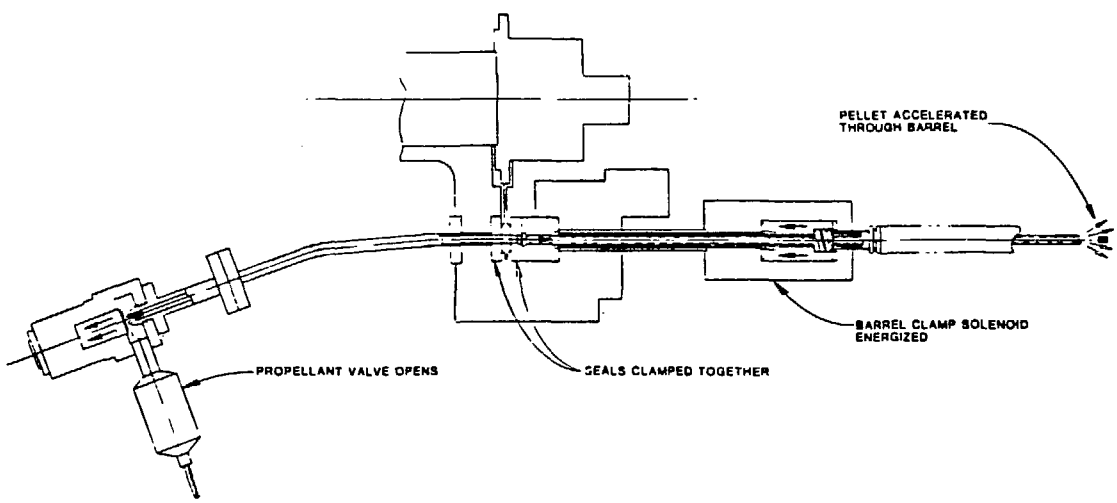


DEUTERIUM PELLET INJECTOR (DPI)

10/30-11/3/85-SKC(VG-19)

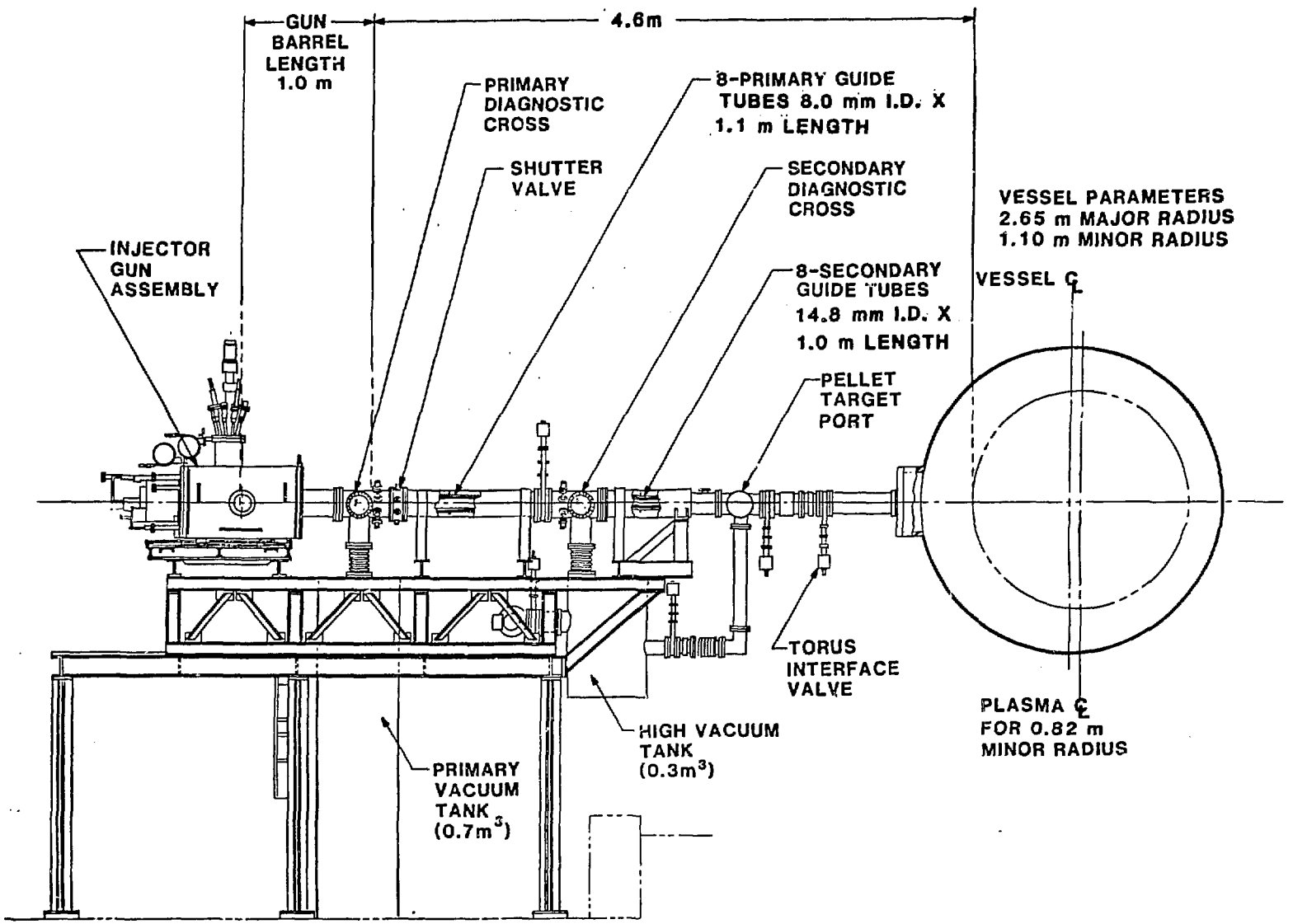


LOADED AND HOLDING



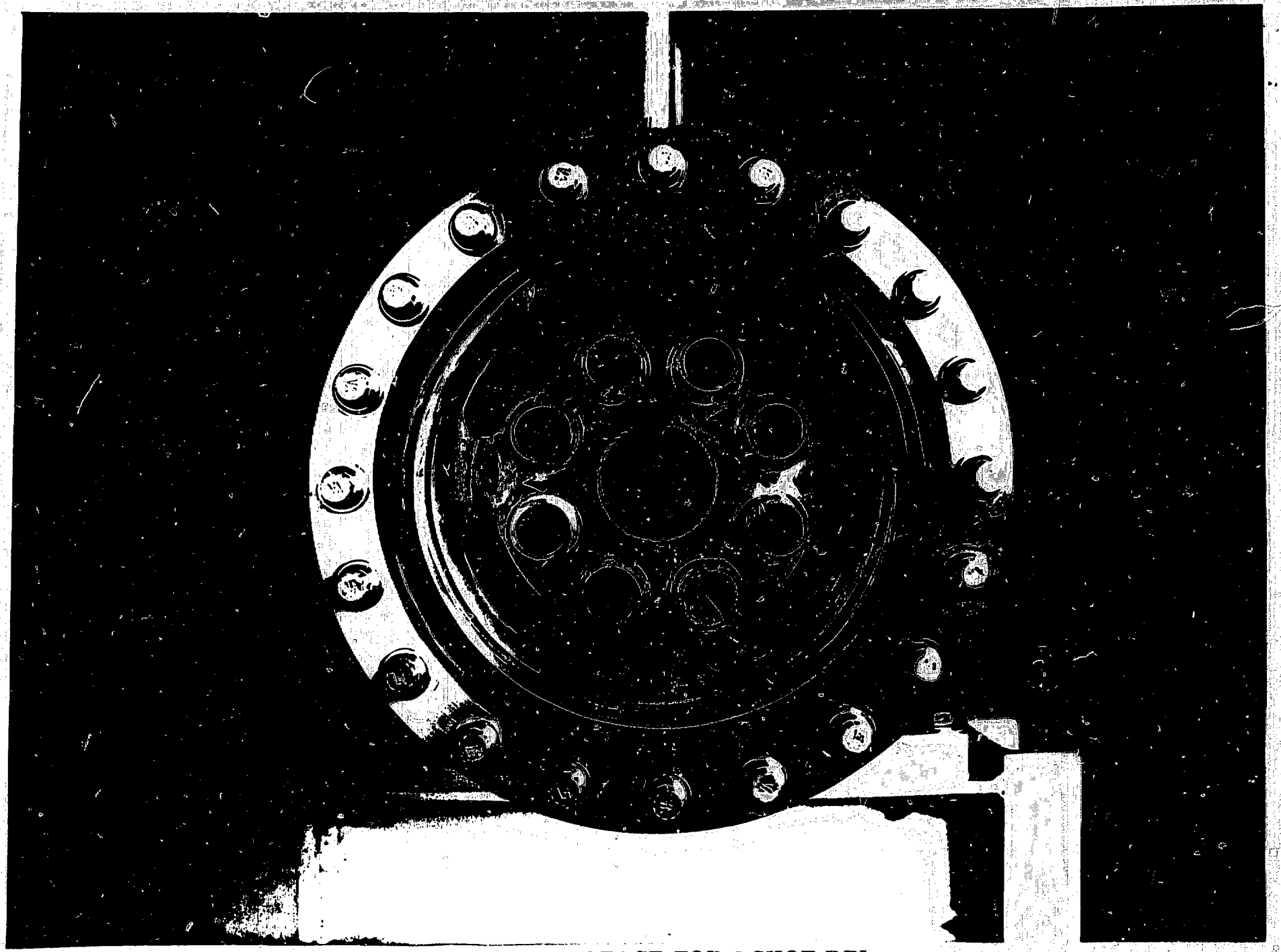
ACCELERATION

SCHEMATIC OF PELLET FIRING SEQUENCE ON DPI



DRAWINC OF DPI ON TFTR TEST STAND

10/30-11/3/85-SKC(VG-21)



ORNL/PPPL INTERFACE FOR 8-SHOT DPI
(OUTLET OF 15-mm-ID SECONDARY GUIDE TUBES ARE SHOWN)

10/30-11/3/85-8KC(VG-23)

Present Status of ORNL Pellet Injectors for TFTR

- RPI will continue fueling experiments on TFTR within the next few months.

- DPI will replace the repeating device as soon as available; assembly phase will begin next month for the new device.