CONF-8309390--Summ. 86014692

JET

SECOND JET WORKSHOP

PELLET INJECTION

Held at Culham on

22 September 1983*

CONF-8309390--Summ.

DE86 014692

Pellet Fueling Programs in the United States

(S. Milora, ORNL)

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SECOND JET WORKSHOP
PELLET INJECTION

MINUTES OF THE WORKSHOP HELD AT CULHAM ON 22 SEPTEMBER 1983

AGENDA

09.00		Introduction	W. Engelhardt	(JET)
09.15	1	Possible Pellet Injection Scenarios for JET, ASDEX Upgrade and Reactors	M. Kaufmann	(IPP)
09.45	1a	Pellet Ablation and Pellet-Plasma Ineraction (Invited Contribution)	L. Lengyel	(IPP)
10.45		COFFEE		
11.00	2	Experience with Pellet Injection in ASDEX discharges	K. Büchl	(IPP)
11.30	3	Proposal for Pellet Injectors in JET	C. Andelfinger	(IPP)
13.00		LUNCH		
14.00	4	Pellet Fueling Programmes in the United States	S. Milora	(ORNL)
14.45		General Discussion		
15.30		TEA		
15.45		Conclusions		
16.45		Transport to Heathrow Airport		

~~P. Rebut asked what is the limitation on the repetitive launching of pellets by the pneumatic method. C. Andelfinger replied that on ASDEX one has two individual cryostats and developing a gun with three barrels; the problem is the thermal separation. At ORNL they have developed already a gun with four barrels.~~

4. Pellet Fueling Programmes in the United States

(S. Milora, ORNL)

S. Milora described the US programme on pellet injection. It has four parts: 1) a confinement experimental program; 2) pellet injector development; 3) theoretical support; 4) tritium pellet study for TFTR.

4.1 Confinement experimental programme

This is based on ORNL supplied devices and encompasses five tokamaks:

a) PDX, 4-shot experiments, completed
b) Alcator C, 4-shot experiments, in progress
c) ISX-B, 4-shot experiments, just started
d) Doublet-III, preparation for centrifuge experiments in 1984
e) TFTR, preparing D_2 experiment in 1985 and T_2 experiment in 1986 for Q=1.

a) PDX 4-Shot Experiment

Pellets were injected into low-power (600kW) plasmas. The H-α emission profiles agreed reasonably well with the new theoretical model at ORNL. The injection of 3 pellets resulted in improvement of β. Varying the heating power up to 3 MW it was found that pellet ablation scales with injection power. They obtained high density, highly peaked profiles. Also, good confinement was observed. The three pellets were fired within 15 ms, the second and third were not much ablated. One could watch their decay for a low temperature plasma. Penetration depths were 25, 30 and 35 cm. The highly peaked density persisted still 70 ms later.

b) Alcator C Experiment

Here too, H-α emission agreed with theory. Record high densities have been achieved: $1.5 - 2 \times 10^{15}$ cm^{-3}. Enhanced inward pinch was observed, with $v \sim 1000$cm s^{-1}. Also improved confinement of $\tau_E \sim$ 30-40 ms was obtained at an $T_e \sim$1.5-1.6 keV.

c) ISX-B Experiment

A similar 4-pellet injector was used as on PDX and Alcator C, shown in Fig. 1. Two or four pellets were injected into a 1 MW discharge, in 5 ms intervals. The resulting density increase in a two-pellet experiment is shown in Fig. 2. There was no decline in T_e, hence there was a ∿30% improvement in energy content. A comparison was made with comparable gas puffing with similar results. A small increase in T_i was observed.

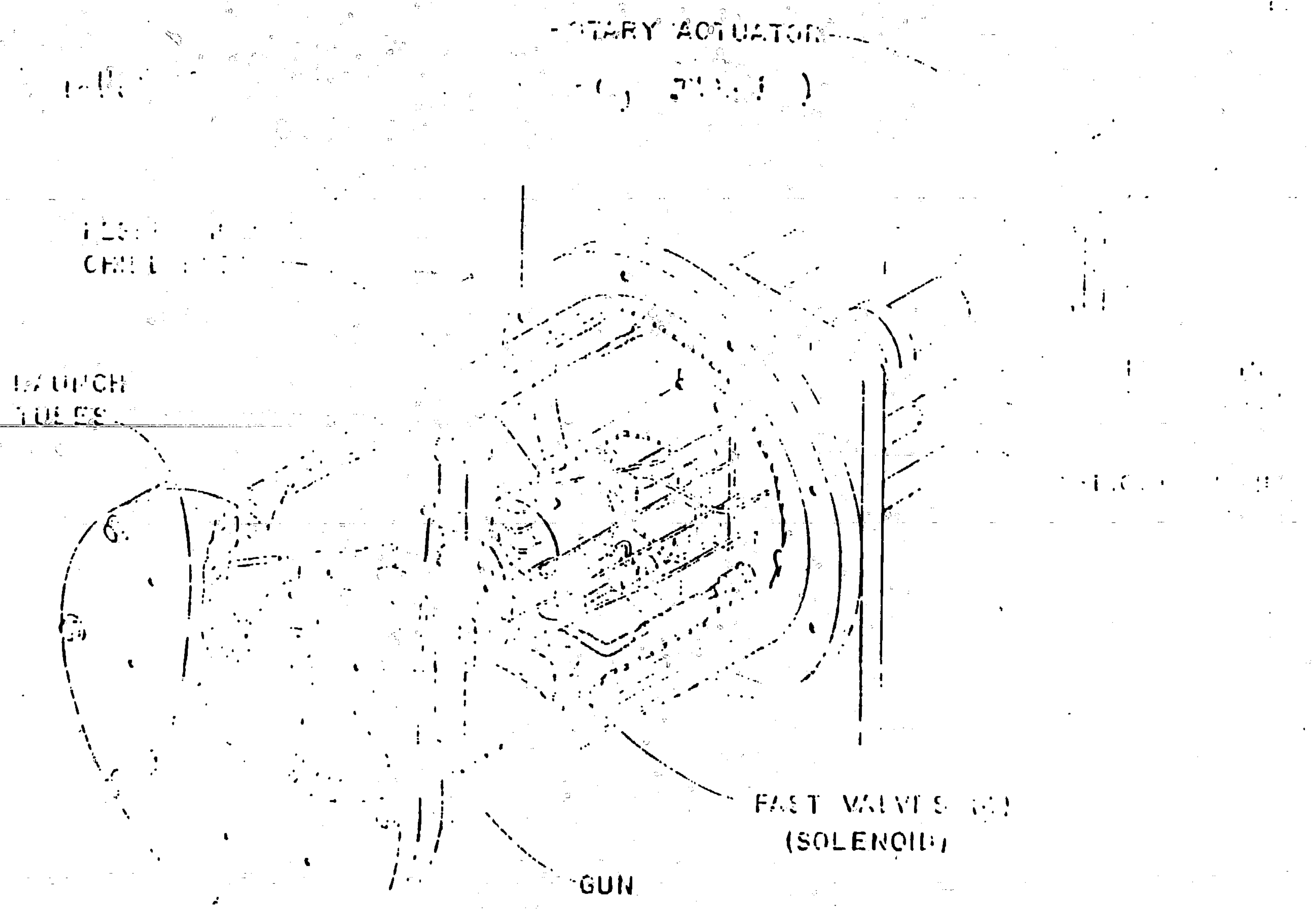
d) Doublet-III Experiment

A centrifuge experiment is in preparation, waiting the approval of DOE.

e) TFTR Plans

The objectives of this project are to obtain Q=1 with minimum T_2 inventory and neutron activation by injecting one or more T_2 pellets at 2 km s^{-1}. For this purpose studies are carried out to optimize pellet fueling using WHIST code, new ablation model and transport coefficient scaled from PDX data. A T_2 injector for eight pellet capability (500 curies) is being designed. A preliminary unofficial schedule is shown in Fig. 3.

The injection study assumes a 1s discharge and a 0.5s, 27MW heating beam. The other assumed parameters are shown in Fig. 4. For the cylindrical T_2 pellet a diameter and length of 3.0 mm,



ig. 1.

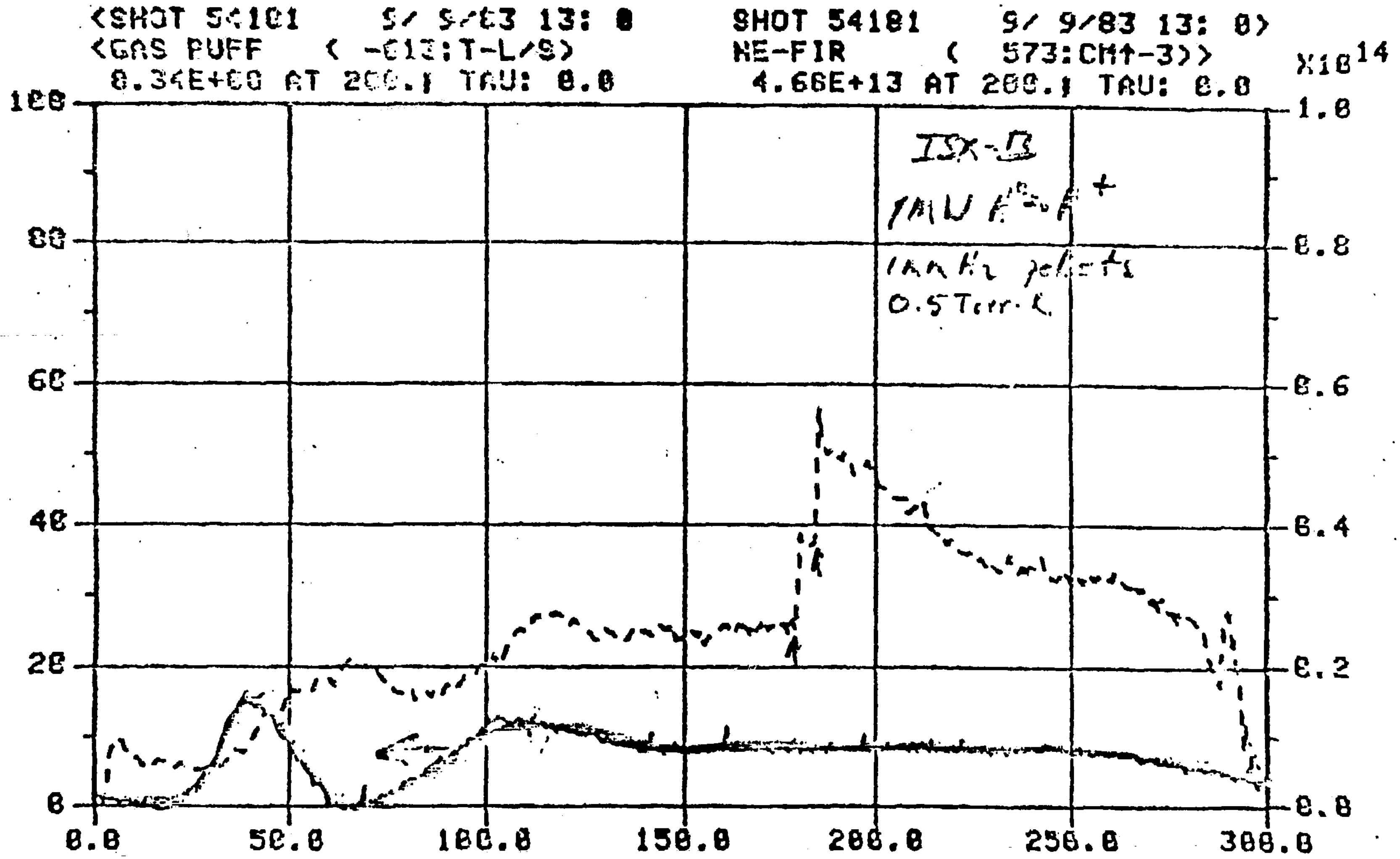
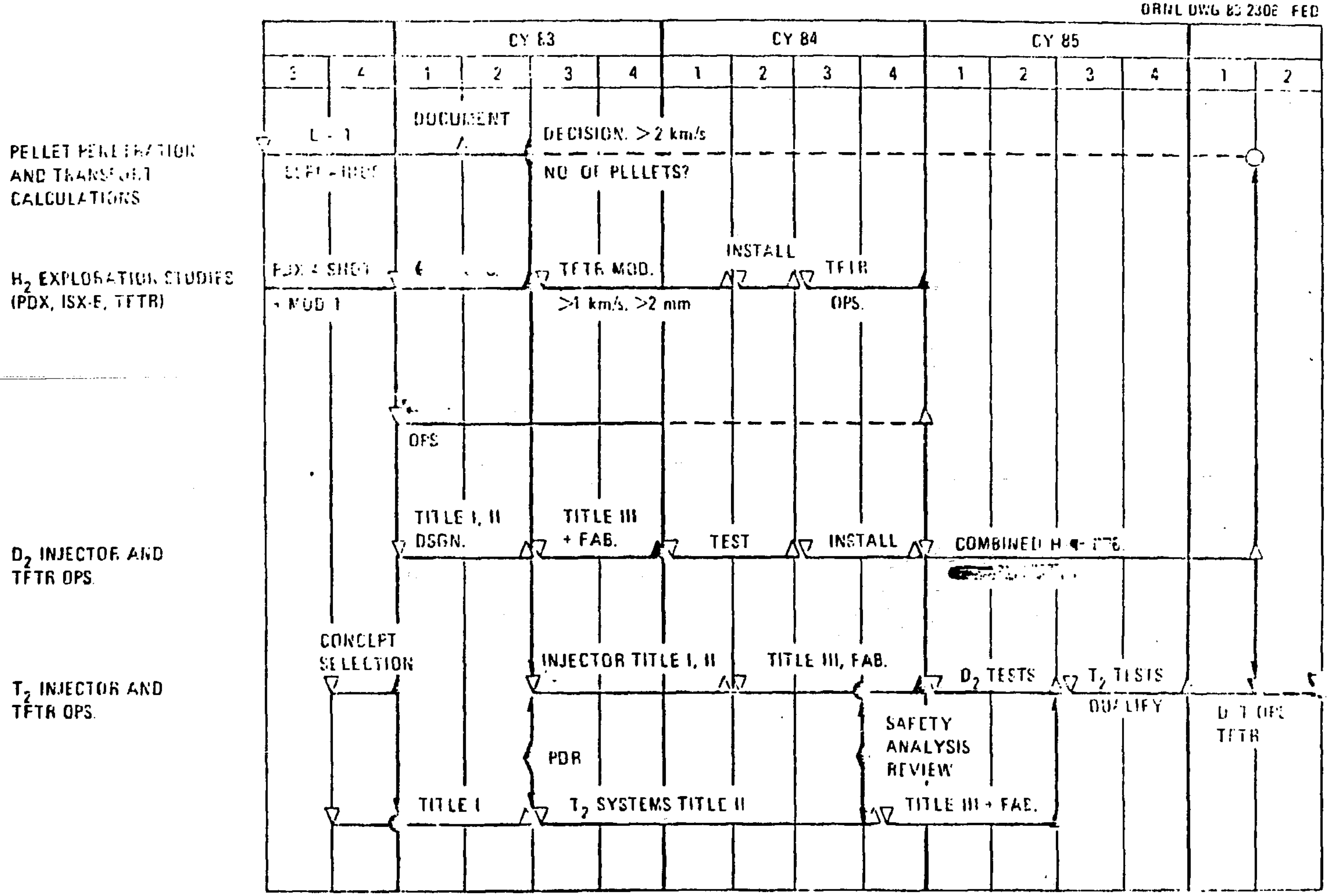

<SHOT 54101 9/ 9/83 13: 0
<GAS PUFF (-613:T-L/S)
0.34E+00 AT 200.1 TAU: 0.0
SHOT 54101 9/ 9/83 13: 0>
NE-FIR (573:CM↑-3)>
4.66E+13 AT 200.1 TAU: 0.0
X10^14
100
80
60
40
20
0
1.0
0.8
0.6
0.4
0.2
0.0
0.0
50.0
100.0
150.0
200.0
250.0
300.0
ISX-B
1MW H^0→H^+
1mm H2 pellets
0.5 Torr·L

Fig. 2

TFTR PELLET INJECTION SCHEDULE (PRELIMINARY)



(July 4)
G = 1

Fig. 3.

TFTR PARAMETERS FOR T PELLET INJECTION STUDIES

Basic parameters:

R_o = 248.0 cm
a = 85.0 cm
B_t = 4.2 T
I_t = 2.5 MA
E_{bo} = 120.0 keV
P_b = 27.0 MW
I_b mix = 51.2 : 31.0 : 17.8

⇓
PULSED FUELING

Pellet ablation includes electrons and fast ions.

Confinement model includes three times neoclassical (Hinton-Hazeltine) conductivity plus an anomalous contribution:

$$\chi_e = 5D = 3.7\times10^3 g(r)\ \mathrm{cm}^2/\mathrm{s}$$

$$g(r) = 1 + 4(r/a)^2$$

Fig. 4.

ornl

1.4×10^{21} atoms, 66 curie has been chosen. No. T_2 recycling is contemplated. Using the WHIST code a high density peak is predicted decaying away slowly. The predicted behaviour of the main parameters for a single pellet is shown in Fig. 5. It is found that Q=1 is achieved at 1.0s.

The pellet injector has been designed. It has a magazine of 8 pellets to load the gun (1500 curies); the pellets injected into the torus represent an inventory of 500 curies. Hot H_2 gas will be used as propellent. The schematic of the TFTR injector is shown in Fig. 6. The side-view of the system is shown in Fig.7 and its plan view in Fig. 8. The schematic of the whole vacuum system is shown in Fig. 9.

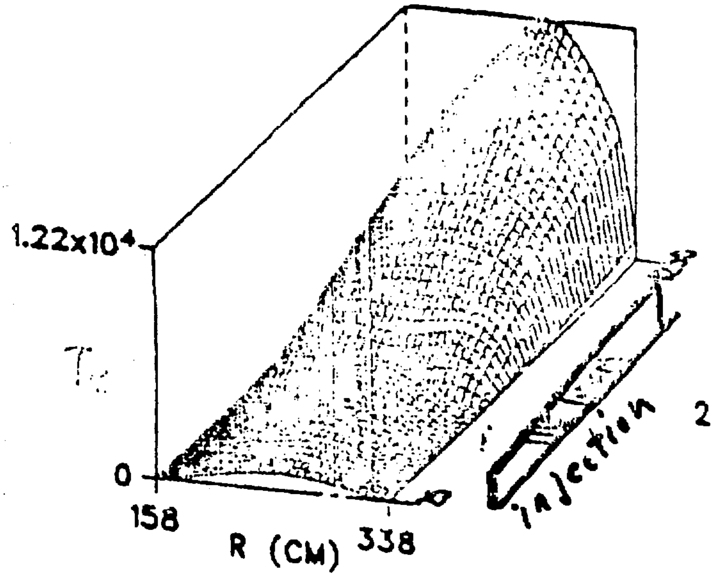
4.2 Pellet Injector Development

A sketch of the repeating pneumatic injector is shown in Fig. 10. Its main characteristics are: velocity $<1300\ ms^{-1}$, size $\sim$ 2.5 mm (ℓ) of D_2, repetition rate 1 p every 2s but with mechanical and electronic capabilities up to 20 p s^{-1}. The main problem is thermal isolation for the multiple pellets. First shots have been completed.

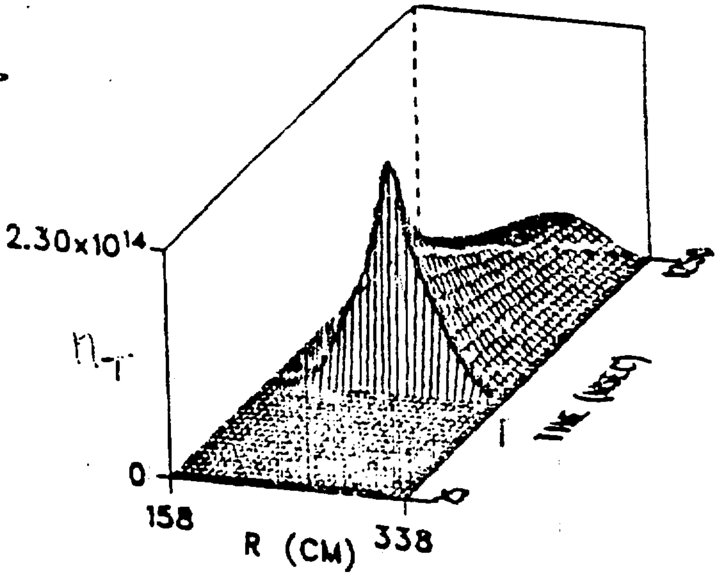
The second development project is the 'snowshoe-arbor' centrifuge, the brainchild of C.A. Foster (ORNL). A schematic diagram is shown in Fig. 11. The extruder system presented a challenge; the latest design is shown in Fig. 12. The present status of the system is the following: velocity $\sim 730\ ms^{-1}$, repetition rate 20 - $42s^{-1}$ for 30s, diameter of cylindrical pellets $\sim$ 1.4 mm. The velocity is limited due to mechanical stress in the pellet. Capabilities of the system: velocity up to 1 kms^{-1} and rep. rate up to 300 ps^{-1}.

The third project is a co-operative one with the University of Illinois to provide an MHD rail gun to further accelerate a pellet after it has reached an initial velocity of $\sim 1500\ ms^{-1}$ by the ORNL gas gun.

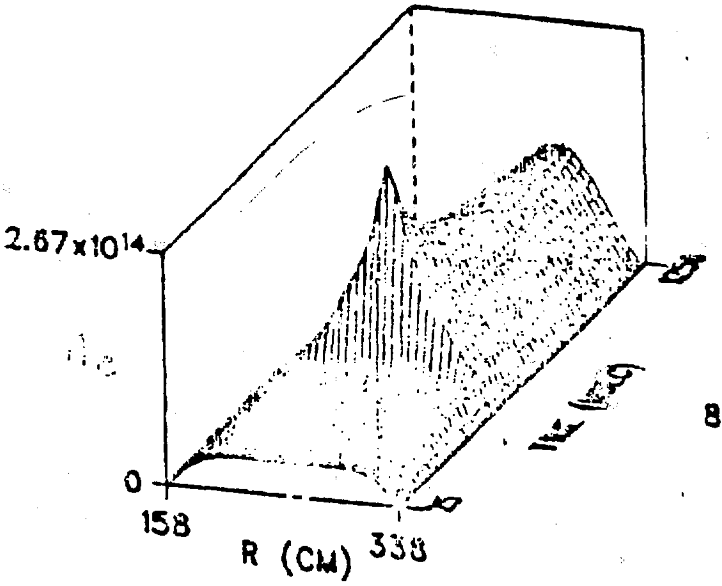
ELECTRON TEMP. (EV)



ION DENS(2) (CM-3)



ELECTRON DENS(CM-3)



ION DENS(1) (CM-3)

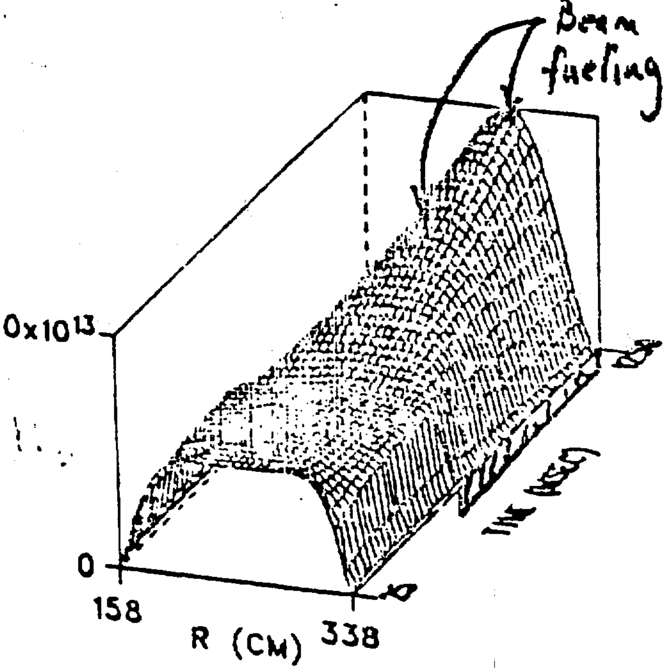


Fig. 3.

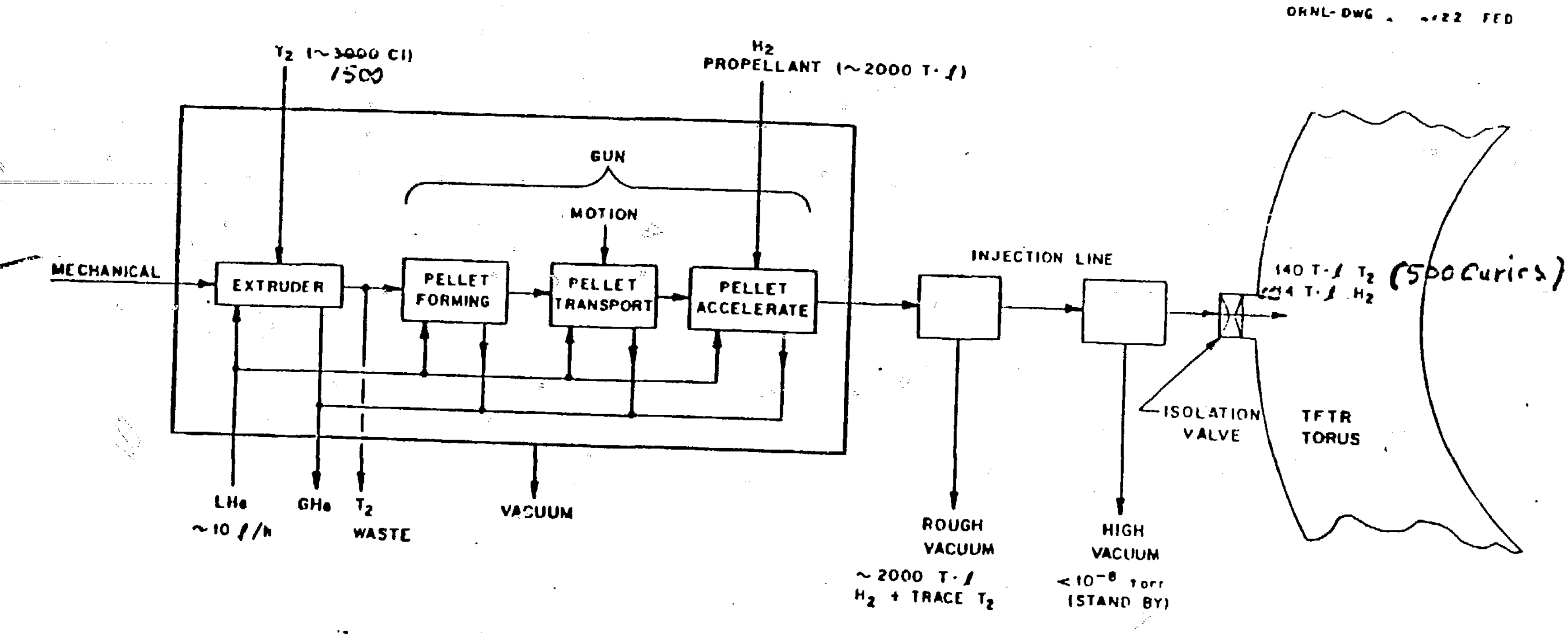

ORNL-DWG [illegible]22 FED
T_2 (~~~3000~~ Ci)
1500
H_2
PROPELLANT (~2000 T·ℓ)
GUN
MOTION
MECHANICAL
EXTRUDER
PELLET FORMING
PELLET TRANSPORT
PELLET ACCELERATE
LHe
~10 ℓ/h
GHe
T_2
WASTE
VACUUM
INJECTION LINE
ROUGH VACUUM
~2000 T·ℓ
H_2 + TRACE T_2
HIGH VACUUM
$<10^{-8}$ torr
(STAND BY)
ISOLATION VALVE
140 T·ℓ T_2 (500 Curies)
4 T·ℓ H_2
TFTR TORUS

Fig. 6.

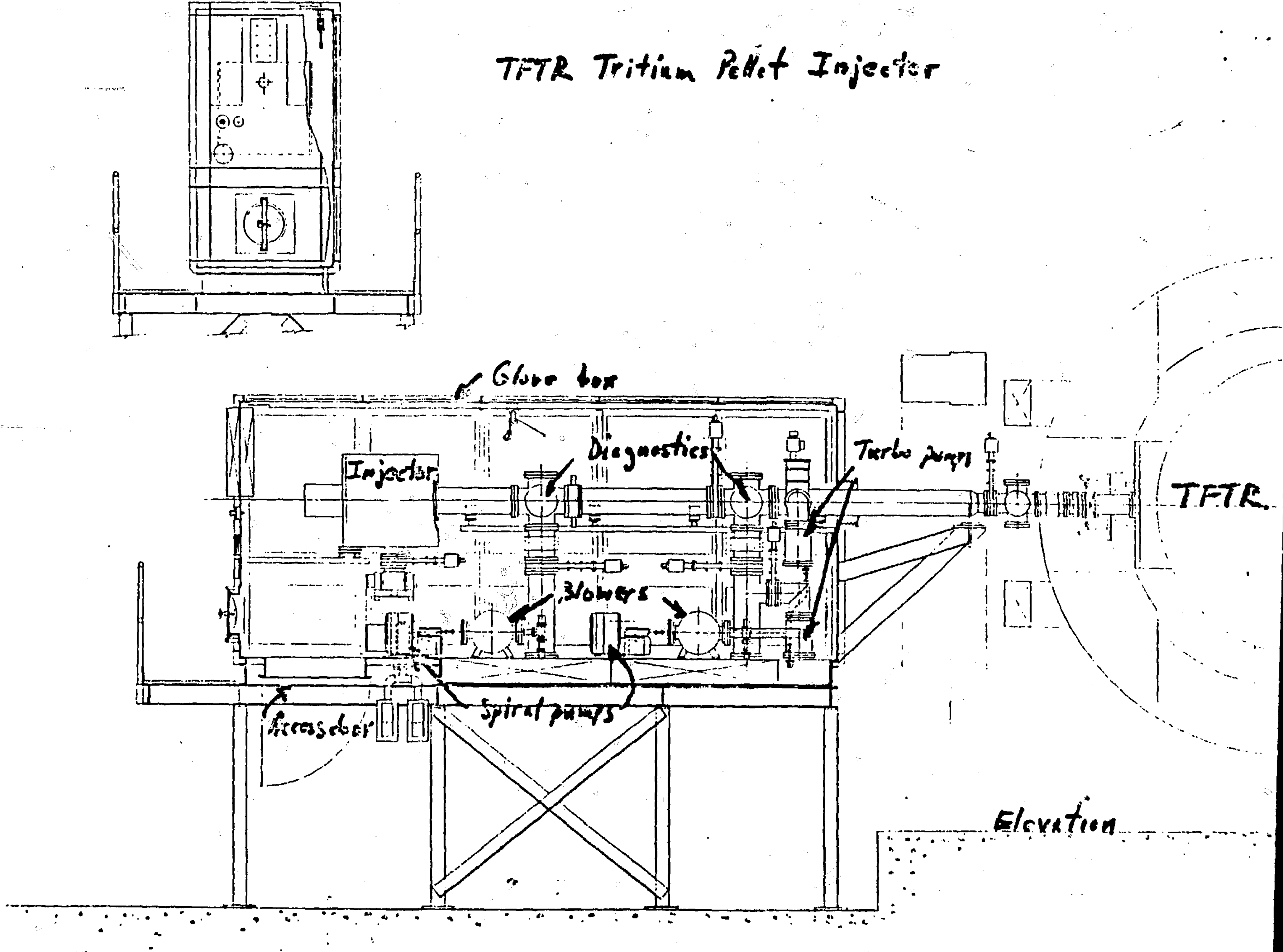

TFTR Tritium Pellet Injector
Glove box
Diagnostics
Turbo pumps
TFTR
Injector
Blowers
Spiral pumps
Access door
Elevation

Fig. 7.

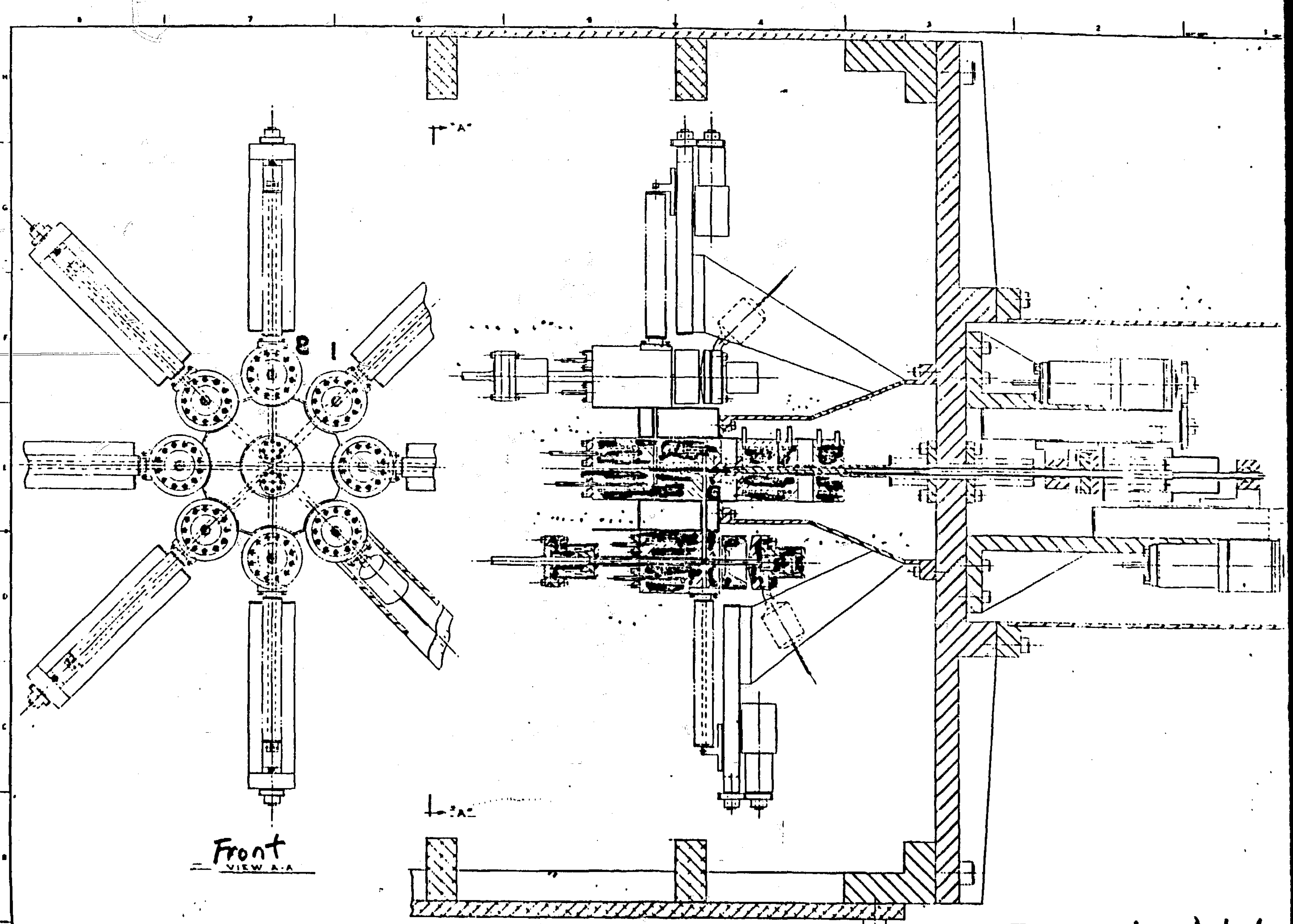


Fig. 8 TFTR T_2 Injector Details

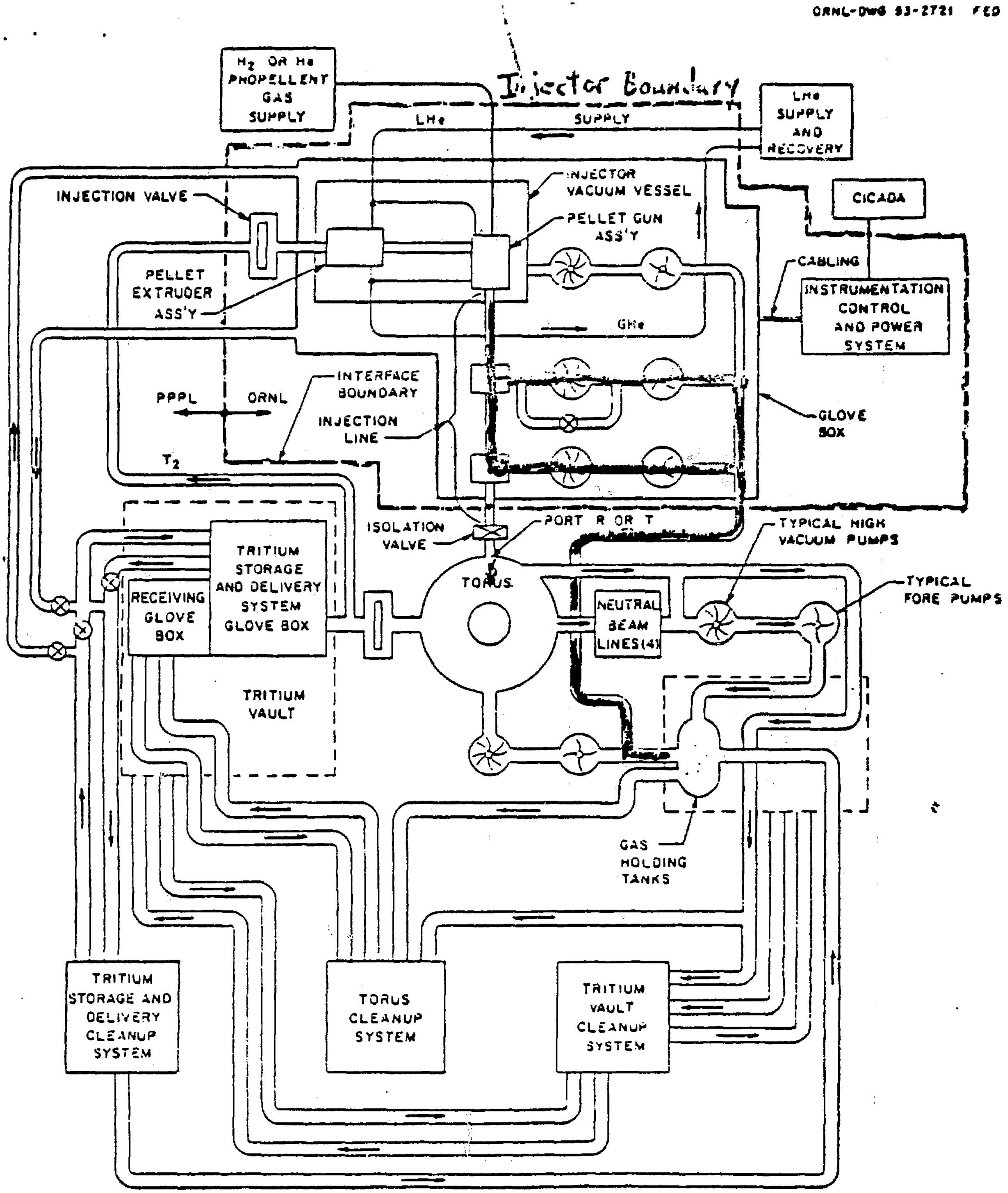
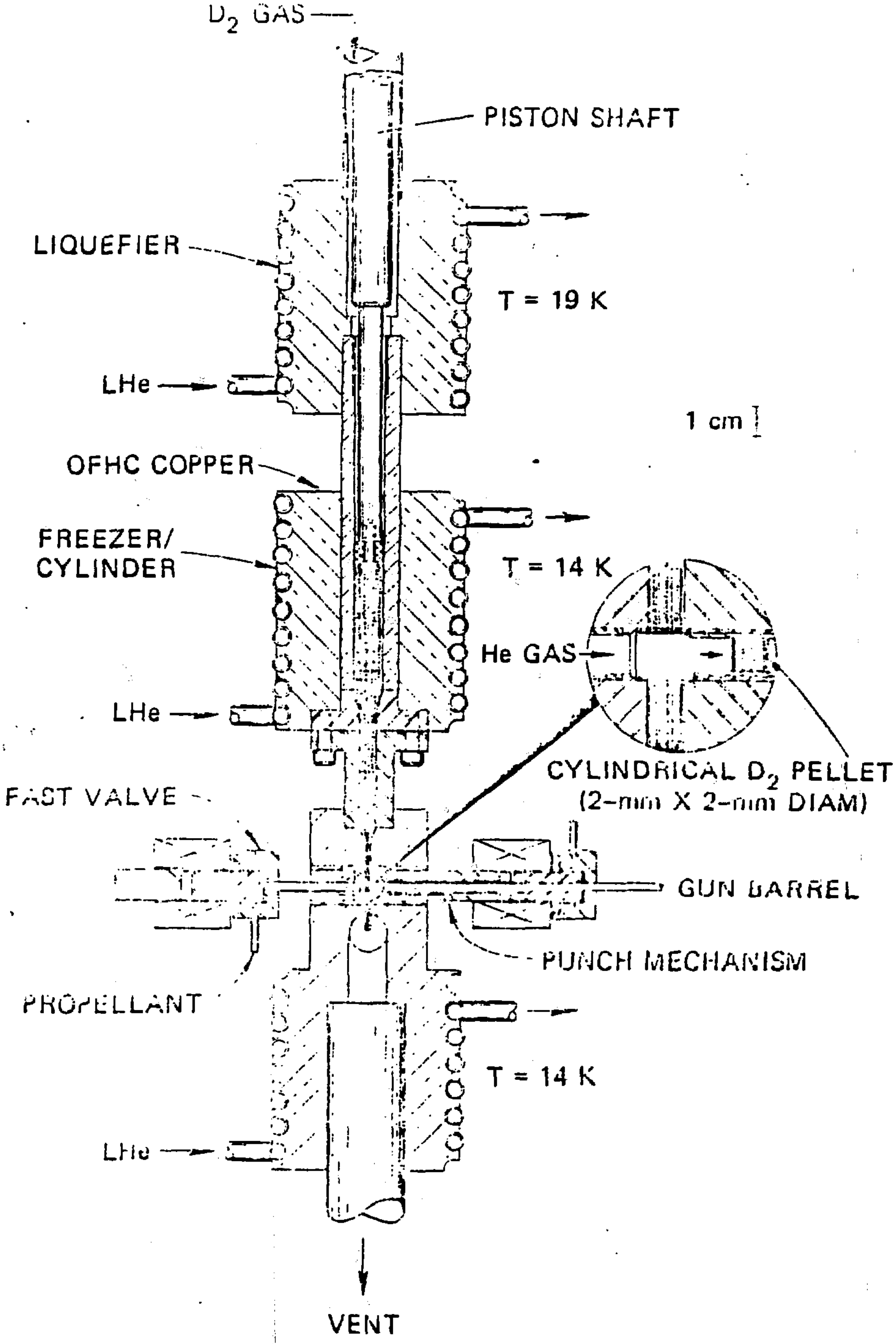

ORNL-DWG 83-2721 FED
Injector Boundary
H_2 OR He PROPELLENT GAS SUPPLY
LHe
SUPPLY
LHe SUPPLY AND RECOVERY
INJECTOR VACUUM VESSEL
INJECTION VALVE
PELLET GUN ASS'Y
CICADA
PELLET EXTRUDER ASS'Y
CABLING
INSTRUMENTATION CONTROL AND POWER SYSTEM
GHe
INTERFACE BOUNDARY
PPPL
ORNL
INJECTION LINE
GLOVE BOX
T_2
ISOLATION VALVE
PORT R OR T
TYPICAL HIGH VACUUM PUMPS
TRITIUM STORAGE AND DELIVERY SYSTEM GLOVE BOX
RECEIVING GLOVE BOX
TORUS
NEUTRAL BEAM LINES(4)
TYPICAL FORE PUMPS
TRITIUM VAULT
GAS HOLDING TANKS
TRITIUM STORAGE AND DELIVERY CLEANUP SYSTEM
TORUS CLEANUP SYSTEM
TRITIUM VAULT CLEANUP SYSTEM

Fig. 9

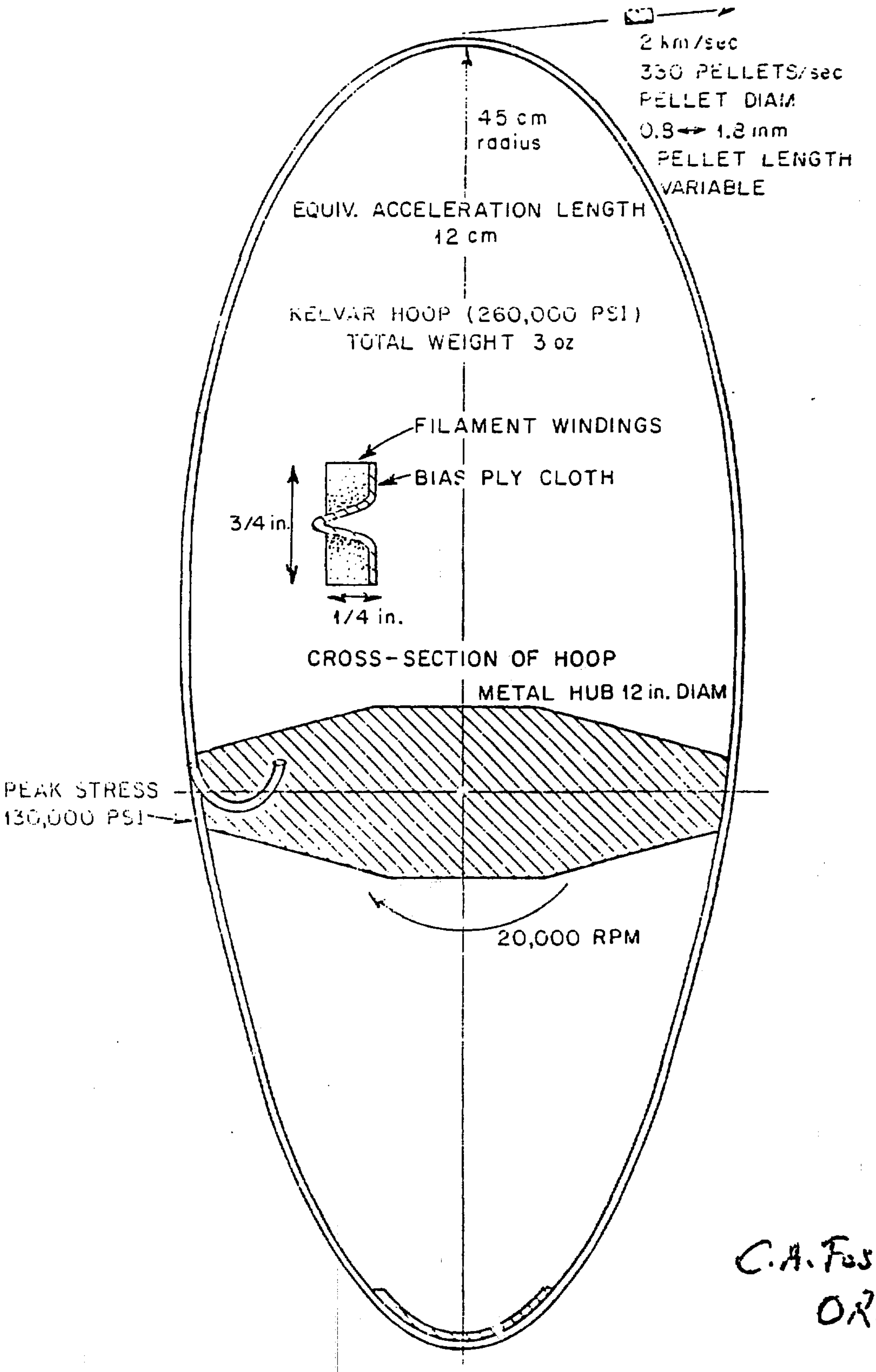
ORNL–DWG 82–23298 FED

Repeating Pneumatic Injector



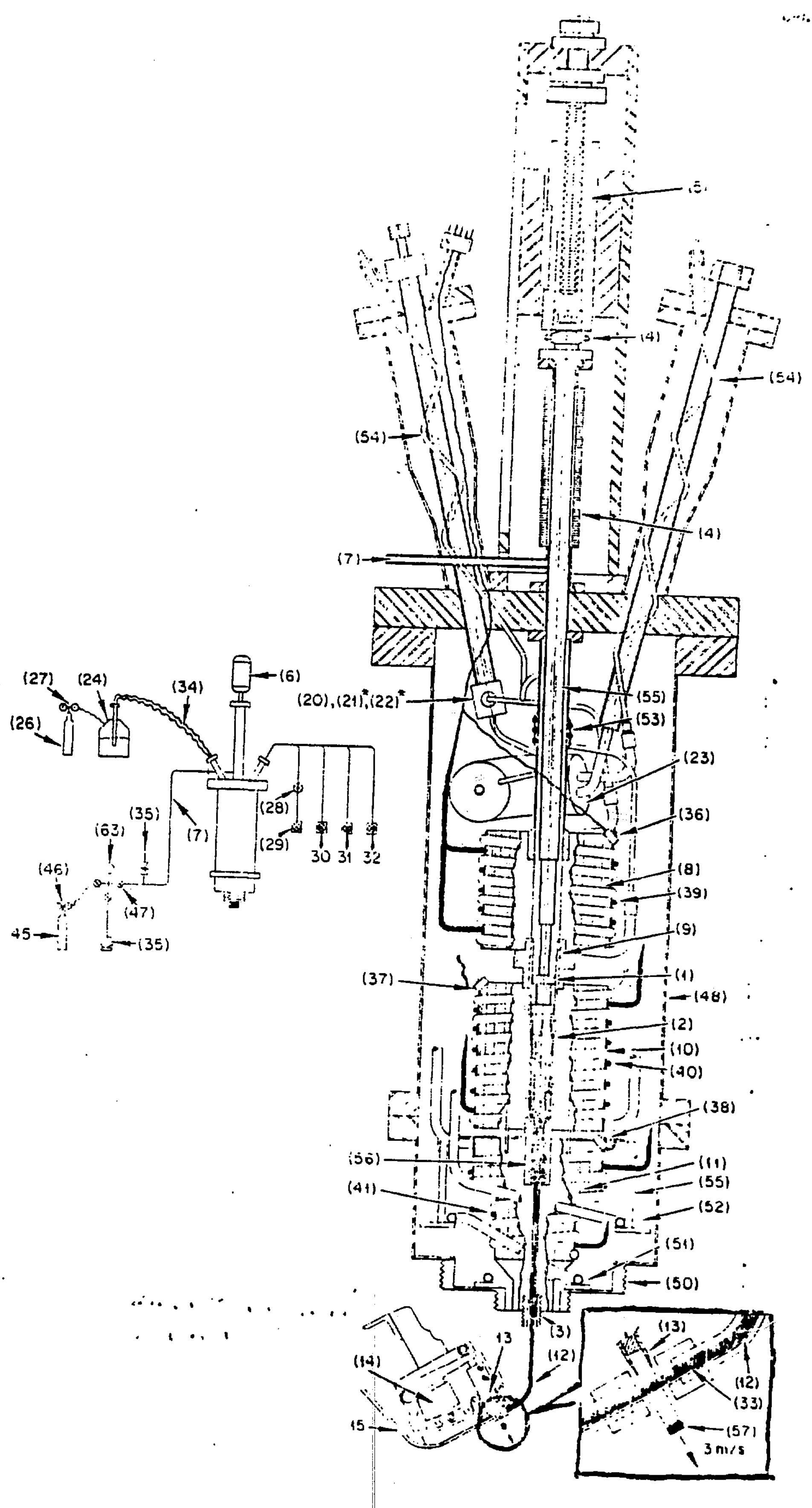
Fig

ORNL-DWG 79-2550 FED



C.A. Foster
ORNL

Fig. 11



* (21),(22) NOT SHOWN FOR CLARITY

Fig. 12

4.3 Theoretical Support

A new algorithm has been proposed for computing the ablation of pellets when hot ions are present. The model is AD HOC in that it assumes old neutral gas shielding solutions for cloud density profile. Hot ions are added into the heat flux terms. Result: ions slow down but still penetrate cloud; electrons are cut-off but they deposit heat in and rarefy the cloud. Ablation rates are higher. The model is no longer simple. Need to know distribution function for hot ions. Requires time dependent Fokker-Planck solution and transport code.

4.4. (See in Section 4.1/e)

Discussion

R. Bickerton asked about the advantage of injecting several small pellets instead of one large one. S. Milora replied that the time interval between pellets is a significant fraction of the energy confinement time and thus the plasma has time for recovery from the density perturbation.

W. Engelhardt asked what are the forces in the gas gun compared with the centrifuge and why do gas gun pellets survive. C. Andelfinger replied that the accelerations are 6 x 10^6 ms^{-2} and 10^6 ms^{-2} in the centrifuge and the gas gun, respectively. The pellet in the gas gun is stabilized by the wall of the barrel. S. Milora added that the pellet survives even in (their) centrifuge.

L. Lengyel asked whether ould be easier to propel the pellet by laser radiation, especially if one used shaped laser pulse. S. Milora answered that none of the advanced techniques have yet been used. For ORNL it is the MHD rail gun the easiest to try. He added, in justification of the centrifuge development that one begins to have problems with the gas at $20ps^{-1}$ in the pneumatic system. M. Kaufmann thought one does not need $20ps^{-1}$ only half of that rate at most. S. Milora remarked that 5% density perturbation is acceptable. M. Kaufmann pointed out that at $2ps^{-1}$ the overall fluctuation is negligible. S.

Milora expressed his opinion that to aim for higher mass is more interesting than for higher frequency. When asked about the nature of the gas, he said H was preferable, given the choice.

~~GENERAL DISCUSSION AND CONCLUSIONS~~

Introducing this section, W. Engelhardt thought that the conclusion is easy as far as the diagnostic application is concerned: the gas gun is well advanced, JET would learn both aboth the plasma and refueling from such diagnostic tool so we should give it the 'go-ahead'. We should discuss what additional diagnostics we need. For the density profile we have the FIR interferometer. For perpendicular observations we can explore the possibilities of the vertical ports. Additional observation in the visible could be done tangentially from another octant or from a small H-α window. Suitable spectroscopy should be arranged to observe impurity transport. The system should be built as soon as possible, without worrying about tritium compatibility.

P. Rebut tended to agree. One should divide the project into two stages: first the pneumatic system should come quickly, made as simple as possible, then decoupled from this a more complex, multiple pellet system. W. Engelhardt remarked that the refueling aspect is unclear: do we want it for producing high density at the limiter? M. Kaufmann replied that one must decide between erosion on the limiter or on the wall. Whatever density one chooses, one ends up with high (>10eV) temperature, i.e. sputtering. W. Engelhardt interjected that JET wants to use a cold mantle. M. Kaufmann thought that there is no chance of reaching <10eV on the limiter, unless one drops the energy content. For the photosphere one needs a density of 3 - 8 x 10^{13} cm^{-3}, in a thick layer. One can have refueling if one has pumping. P. Rebut objected that there is no need for refueling, only fueling. In his opinion four pellets are sufficient and pellet injection is certainly beneficial: it gives an additional 'knob'. He always prefers a 'knob' to an observation. Even if JET does not benefit from it directly, it provides information ~~for reactors.~~