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CIT FUELING

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CIT Conceptual Design Review

Princeton, NJ

January 19-21, 1988

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MASTER

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OUTLINE

Fueling issues

Pellet injector technology

Pellet ablation and penetration

Particle confinement

Fueling scenarios

Summary

FUELING ISSUES

Sustain centrally peaked density profiles:

- Enhanced fusion rate and ignition margin
- Possibly enhanced energy confinement
- Pellet penetration as deep as possible
- Competition between diffusive and pinch terms
- Possible deleterious role of locked modes

Minimize tritium injected into torus:

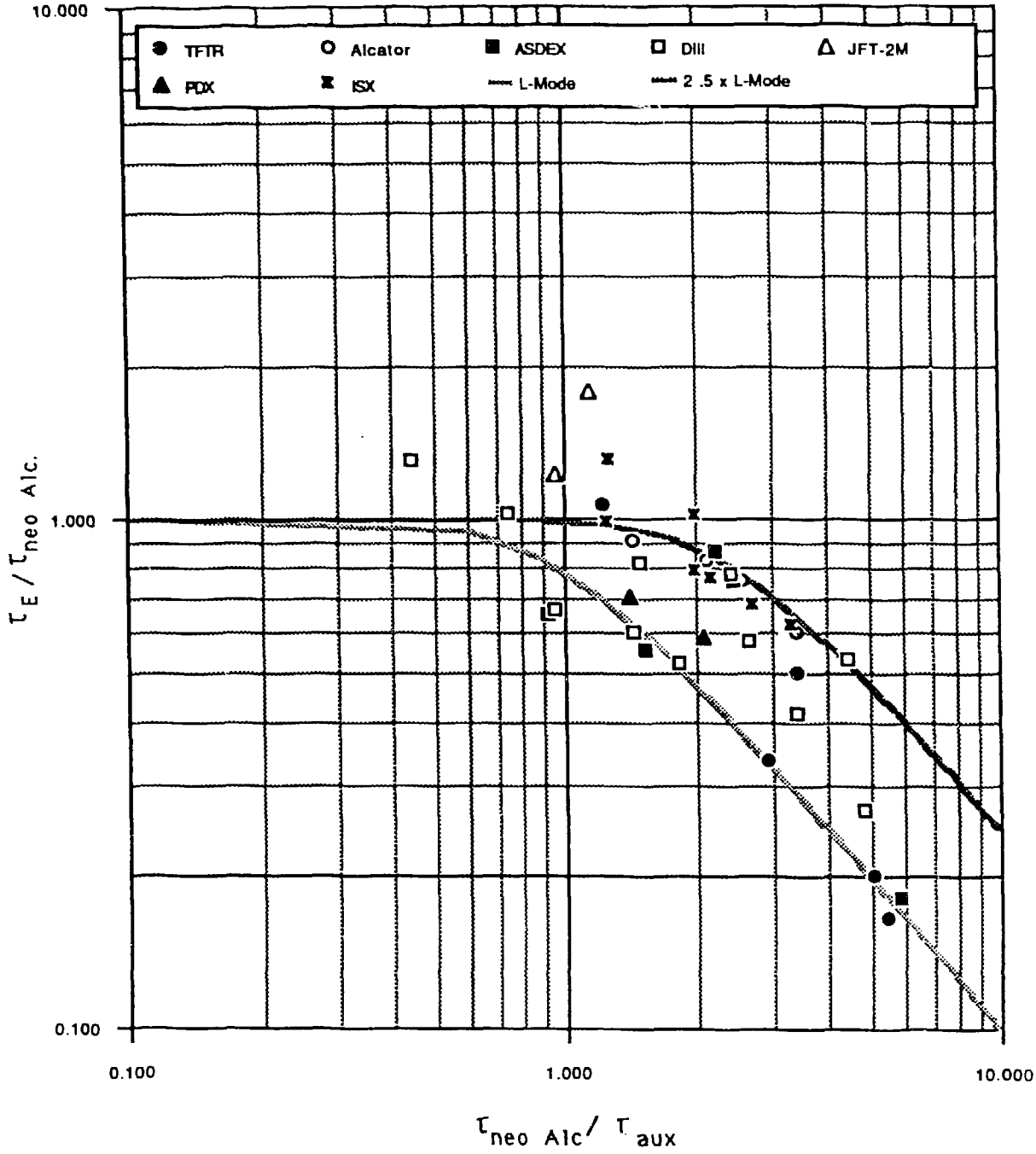
- Delay T injection until just prior to auxiliary heating
- Utilize T pellet injection to maximize T particle confinement

Pellet injector technology:

- Minimize T consumption and inventory in gun(s)
- Maximize reliability
- Baseline injector: current technology for pellet size, velocity, and repetition rate (TFTR and JET)
- Exploratory injector: few pellets at high velocity for burn phase

PELLET CONFINEMENT RESULTS

S.L. MILORA, ORNL



SPECIFICATIONS FOR CIT PELLET INJECTOR(S)

	CIT Requirement	Achieved (1-88)
• Pellet Diameter (mm)	3–4 ($\Delta n/n \sim 0.2$–0.4)	1–6 mm
• Pellet Species	H_2, D_2, T_2	H_2, D_2
• Max Repetition Rate (Hz)	10	6 (pneumatic) 30 (centrifuge)
• Pellets Per Shot	40	~100 (pneumatic) 80 (centrifuge)
• Velocity (m/s)		
Minimum	1500	2000 [2] (H_2) single-stage pneumatic
Goal	1500–5000 [1] (T_2)	3400 [2] (D_2) 2-stage gun
• Reliability	High (~ 0.9)	Variable [3]

1 Required for multiple pellets
2 Achieved in single-shot development guns
3 Where reliability has been designed for, typical values are 0.7–0.9

1-11-88
MJG

COMPARISON OF JET AND CIT PELLETS

Machine Parameters

Parameters	JET	CIT
R_o (m)	2.96	1.75
a_o (m)	1.20	0.55
κ	1.8	2.0
B_{To} (T)	3.4	10.0
I_o (MA)	7.0	9.0
Calculated Parameters		
$< n_{\mathrm{Mu}} > (10^{20}\,\mathrm{m}^{-3})$	0.6	3.1
$V_p\,(\mathrm{m}^3)$	151.0	19.7
$N_{\mathrm{Mu}}\,(10^{20})$	91.0	61.0

Pellet Sizes and
Fraction of Murakami Density Limit

Spherical Radius r_p (mm)	N_p 10^{20}	% JET	% CIT
1.2	4.6	5.0	
1.25	5.2		8.5
1.4	7.2		
1.5	8.9		14.5
1.75	14.2		
2.0	21.0	23.0	34.5
3.0	70.9	78.0	

PELLET INJECTOR TECHNOLOGY DEVELOPMENT IN SUPPORT OF CIT

- **TRITIUM PELLET FABRICATION**

  The single-shot tritium-proof-of-principle (TPOP) injector has been fully qualified with deuterium pellets and is being shipped to TSTA this month for initial tritium pellet formation / acceleration experiments. These initial experiments are scheduled for completion by June 1988.

- **MULTIPLE PELLET FABRICATION**

  Only modest changes to existing JET repeating pellet injector technology are required to meet the CIT repetition rate. Concepts are being conceptualized which would minimize the excess tritium inventory for fabrication of multiple pellets to ease operational constraints on CIT.

1-11-88
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PELLET INJECTOR TECHNOLOGY DEVELOPMENT IN SUPPORT OF CIT (con't.)

- PELLET VELOCITY

Ongoing Programs	Velocity Goal
Single-stage pneumatic improvements (ORNL, EC)	2 – 2.5 km/s
Electrothermal guns (ORNL, Risø) (hydrogen propellant gas arc)	2 – 5 km/s
Two-stage pneumatic guns (EC)	2 – 5 km/s
Two-stage railguns (U. of IL)	2 – 5 km/s
Electron beam pellet ablation (ORNL)	2 – 10 km/s

- PELLET RELIABILITY

Pellet injector reliability data from TFTR, JET, and Tore Supra will be complied and analyzed to optimize future designs.

The possible cancellation of the tritium pellet injector for TFTR represents a significant loss of design/operating experience which would have benefited the CIT pellet fueling system.

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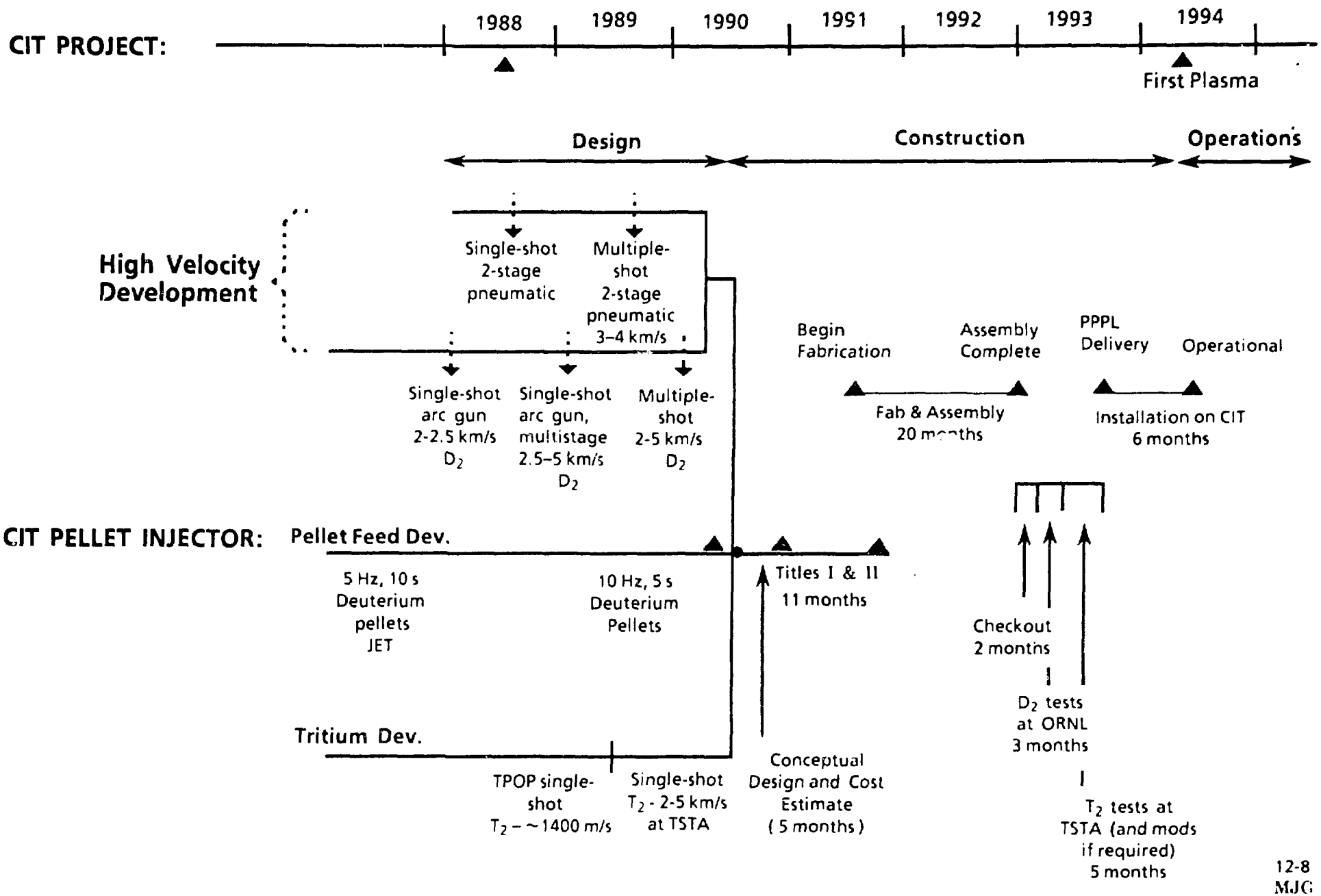
CIT PELLET INJECTOR PROJECT SCHEDULE



12-8
MJG

PELLET ABLATION AND PENETRATION

Neutral gas and plasma shielding model:

- Dense, spherical neutral gas layer surrounding pellet provides primary shielding
- Dense plasma extending along the magnetic field provides additional shielding
- Maxwellian distribution of electrons and slowing-down distribution of alphas and beam ions incident from the plasma

Fast ion and alpha effects:

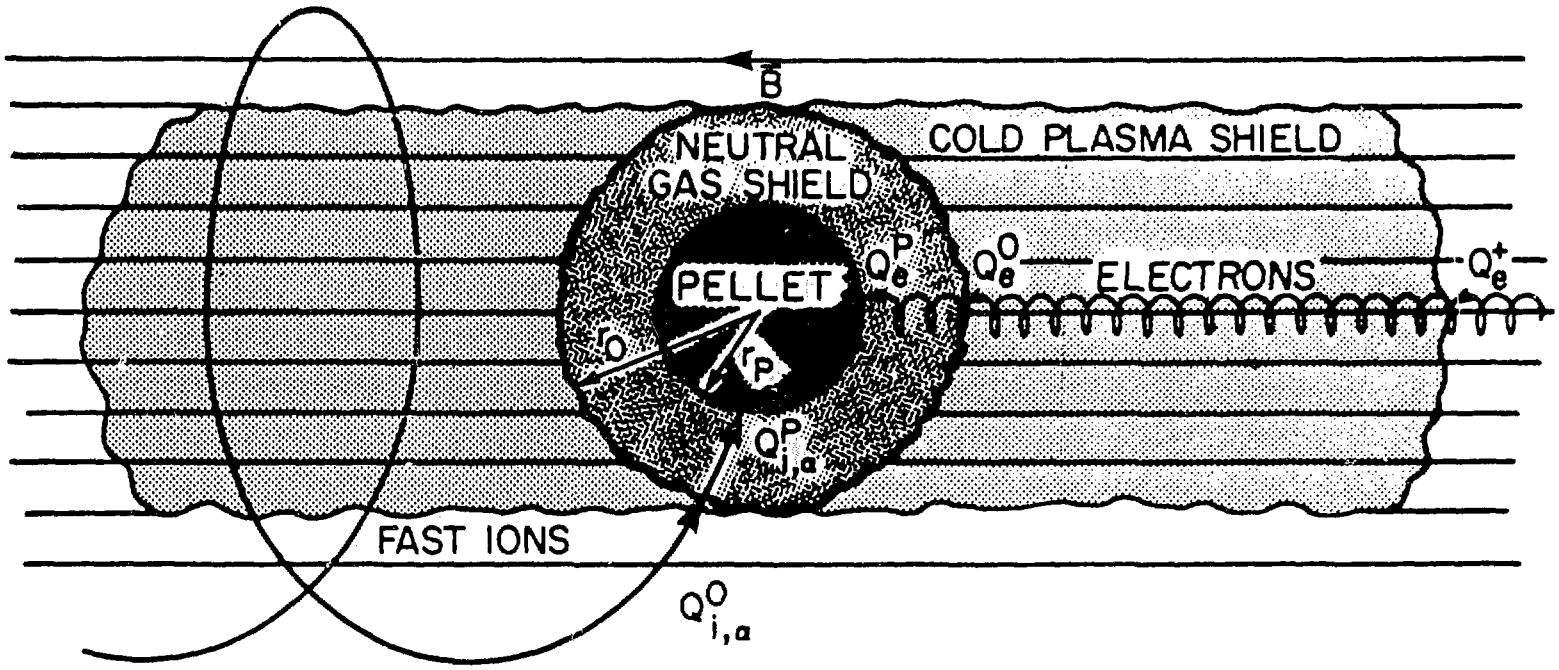
- Fast ions from ICRH heating probably not important when resonance zone is near the plasma center
- Fast alphas should be unimportant since ehield established by the electrons should stop 3.5 MeV alphas

References:

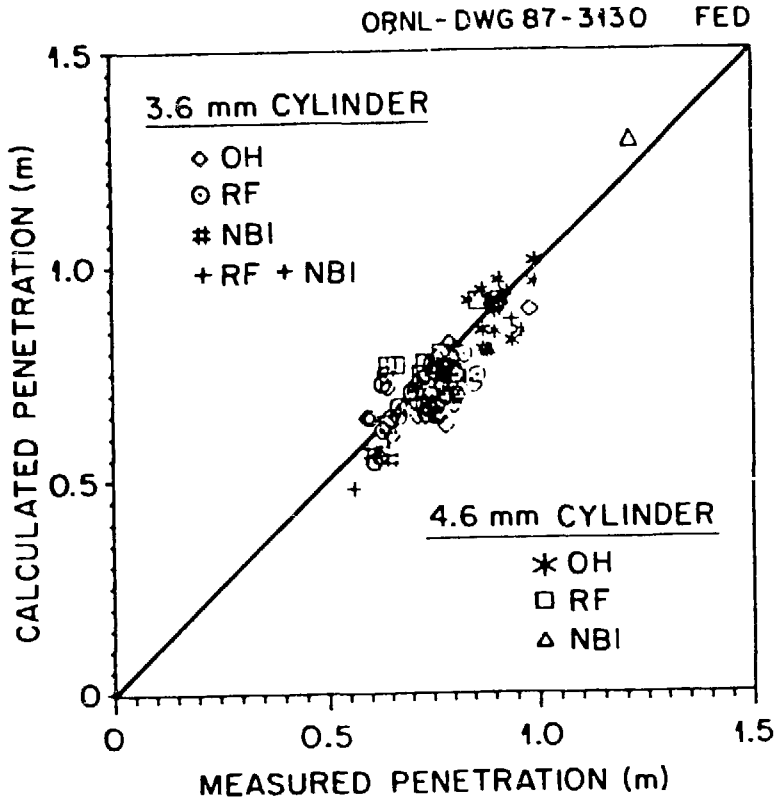
- W. A. Houlberg, S. L. Milora, and S. E. Attenberger "Neutral and Plasma Shielding Model for Pellet Ablation," ORNL/TM-10556, to be published in *Nuclear Fusion*
- M. L. Watkins, W. A. Houlberg, A. D. Cheetham, et al., "A Model for Pellet Ablation in JET," 14th EPS, Madrid, p. 201.

NEUTRAL GAS AND COLD PLASMA SHIELDING

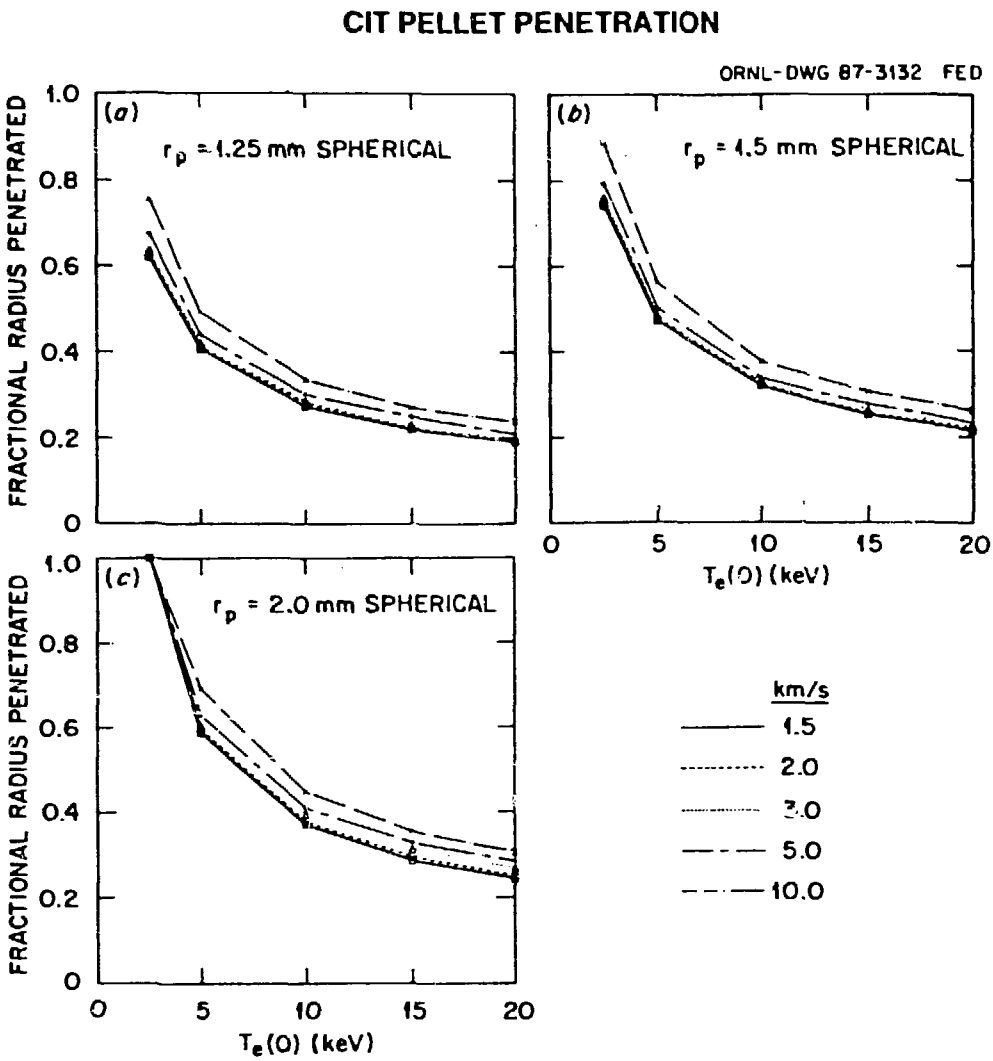
ORNL-DWG 87-2260 FED



JET SINGLE-SHOT PELLET PENETRATION



- Good agreement between calculated and observed penetration in JET under a wide range of conditions
- No significant fast ion effects from NBI or ICRH observed



- Good penetration for all pellets in Ohmic plasmas
- Weak velocity dependence for $v_p > 1.5\,\mathrm{km/s}$

PARTICLE CONFINEMENT

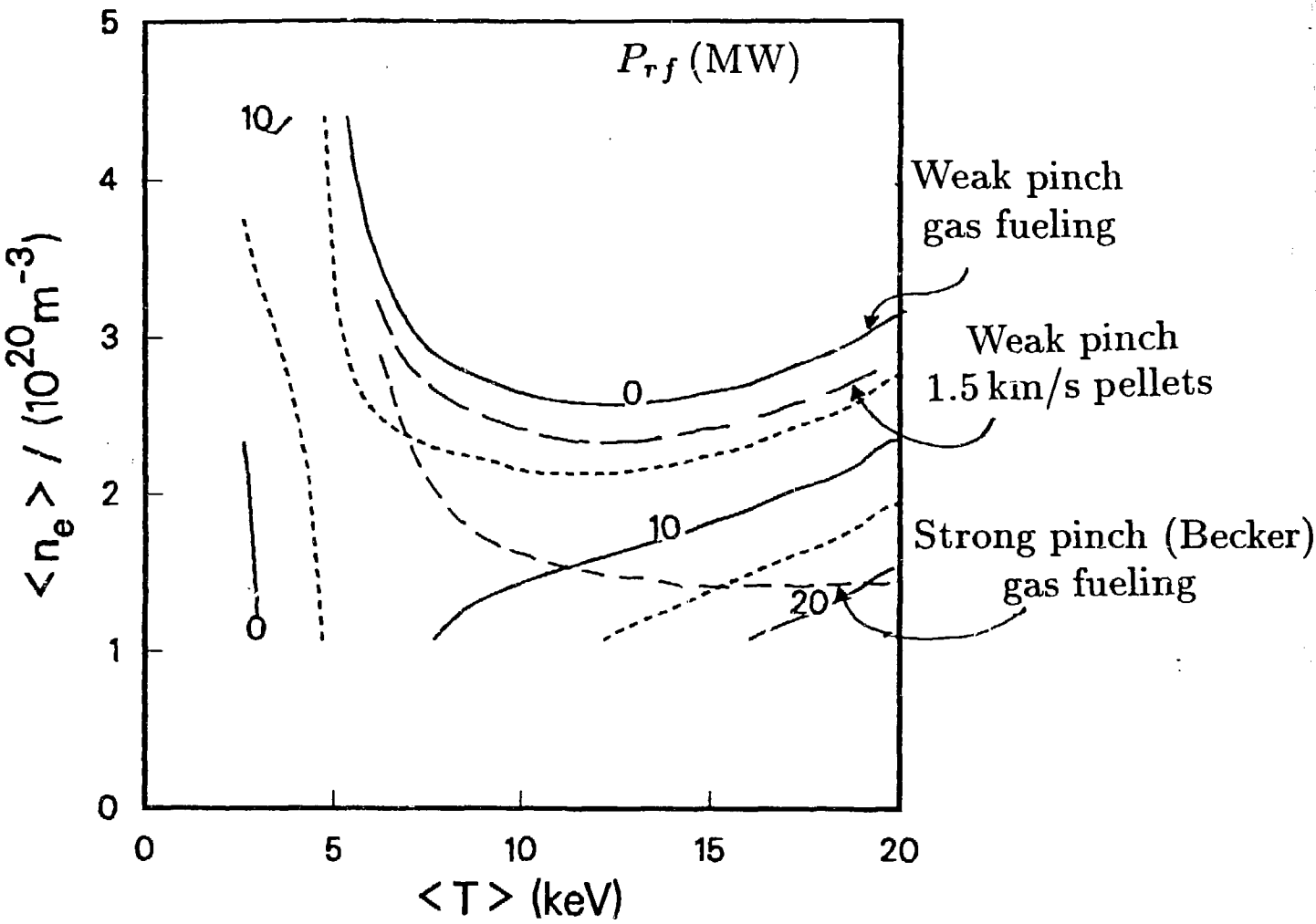
Present models:

- Include Ware pinch and modest anomalous pinch that leads to $n(r) \approx n_o[1 - (r/a)^2]^{1/2}$ under conditions of gas fueling
- Scale anomalous particle losses the same as anomalous energy losses

Further study:

- Improve particle transport models (diffusive and pinch terms): scaling under H- and L-Mode conditions
- Understand the role of locked modes in particle confinement and means of avoidance

DENSITY PROFILE EFFECTS IN CIT



FUELING SCENARIOS

Pellet injection:

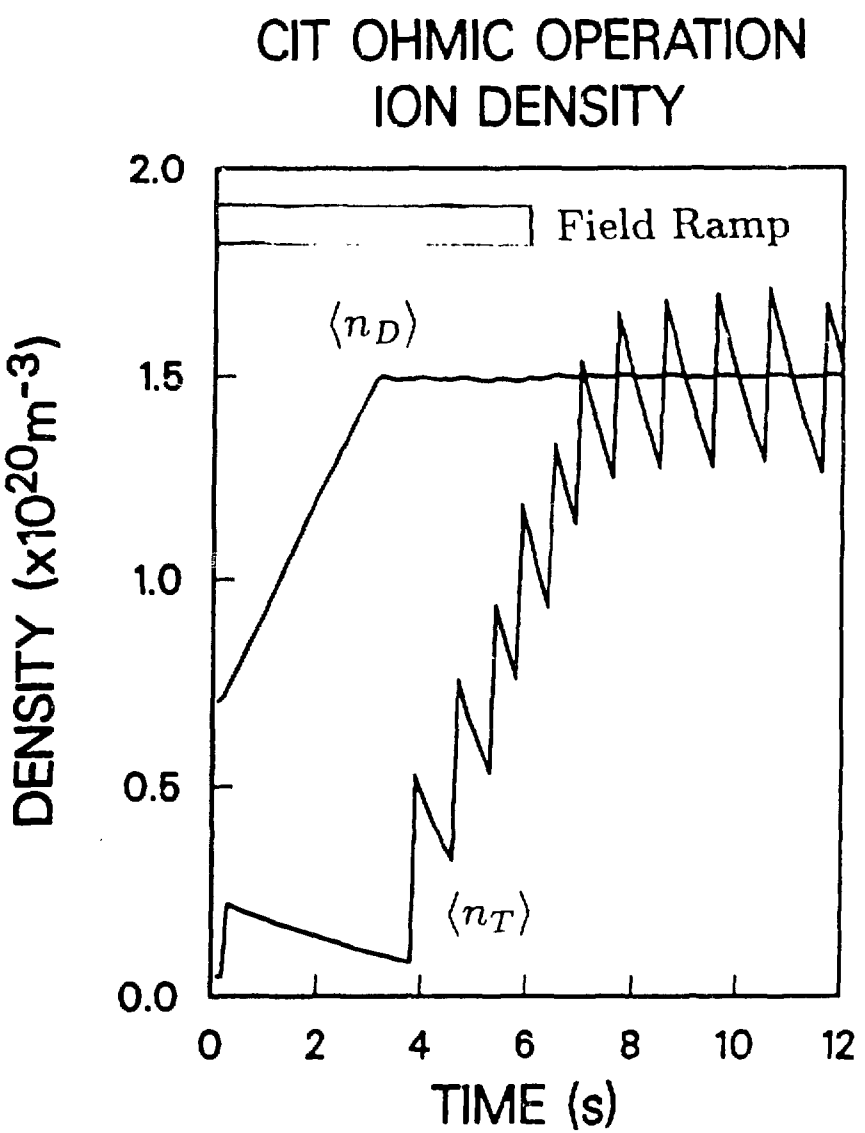
- Injection prior to auxiliary heating can produce strongly peaked density profiles
- Defer tritium injection until late in the density ramp

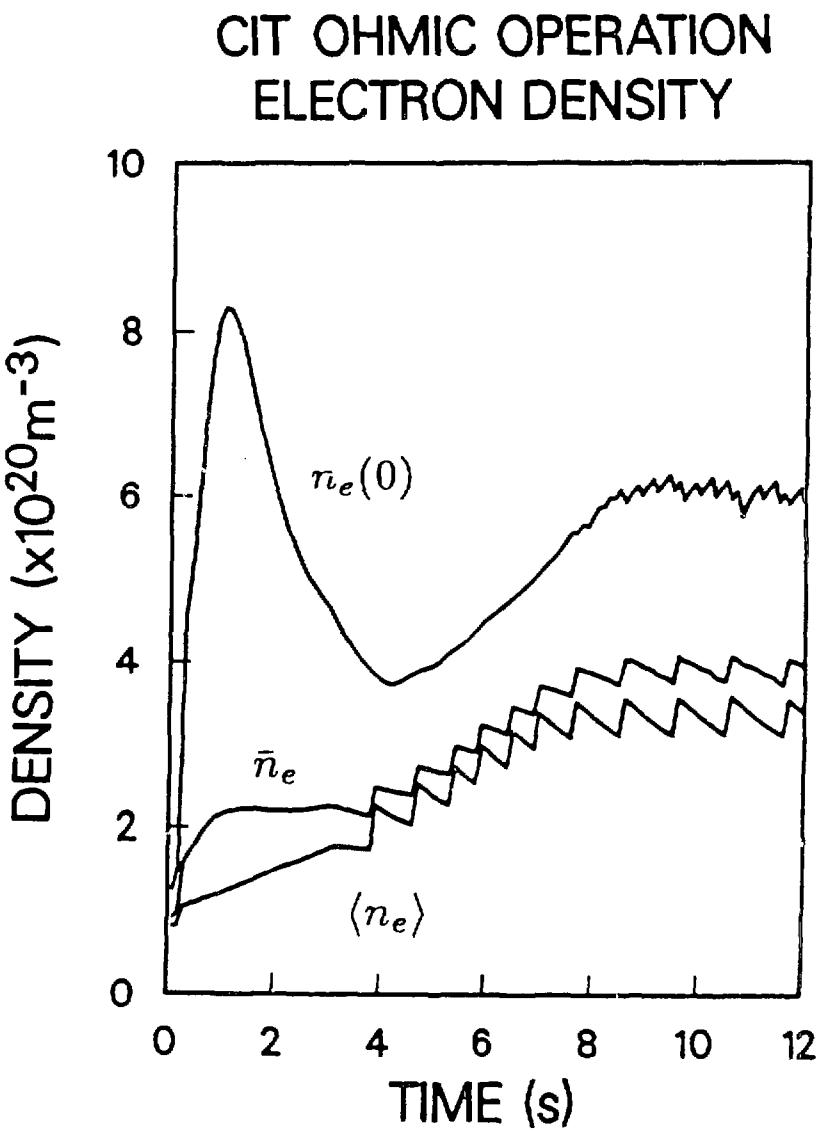
Gas injection:

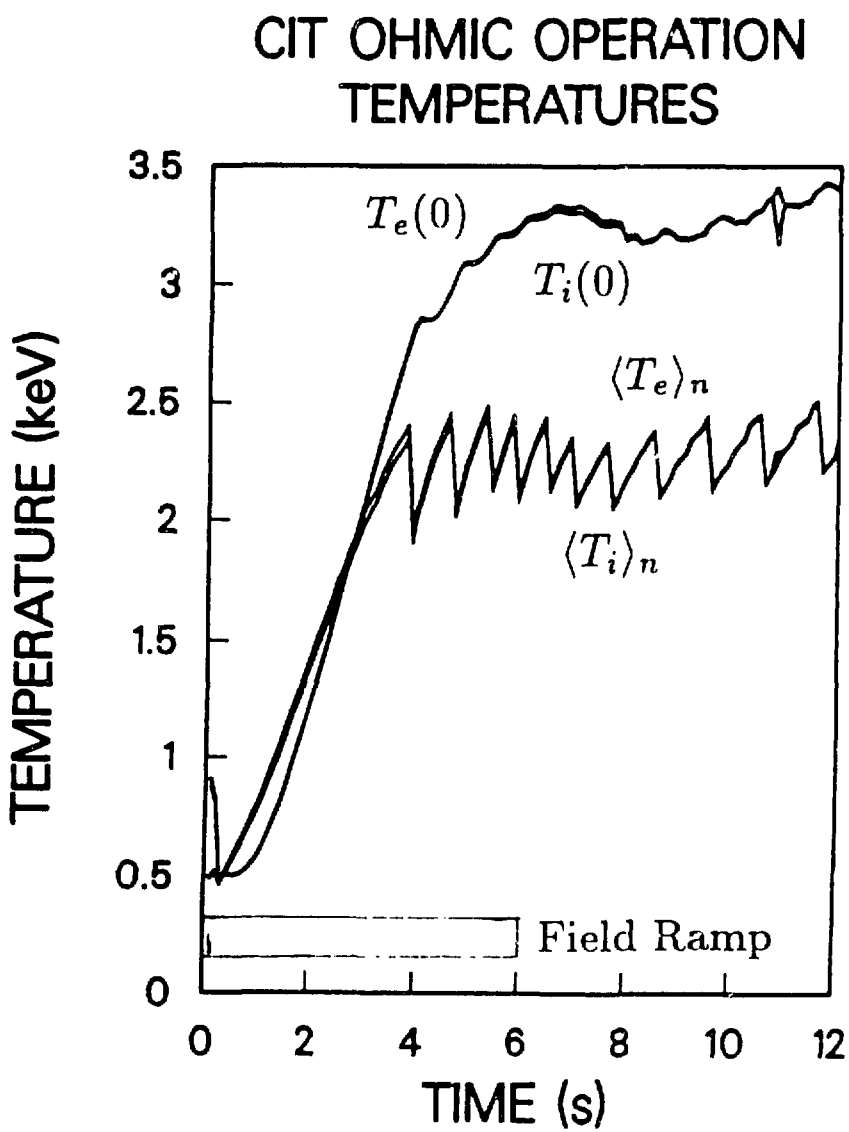
- Provides some control over plasma edge conditions, but masked by recycle
- Primarily reserved for deuterium injection because of tritium inventory issues

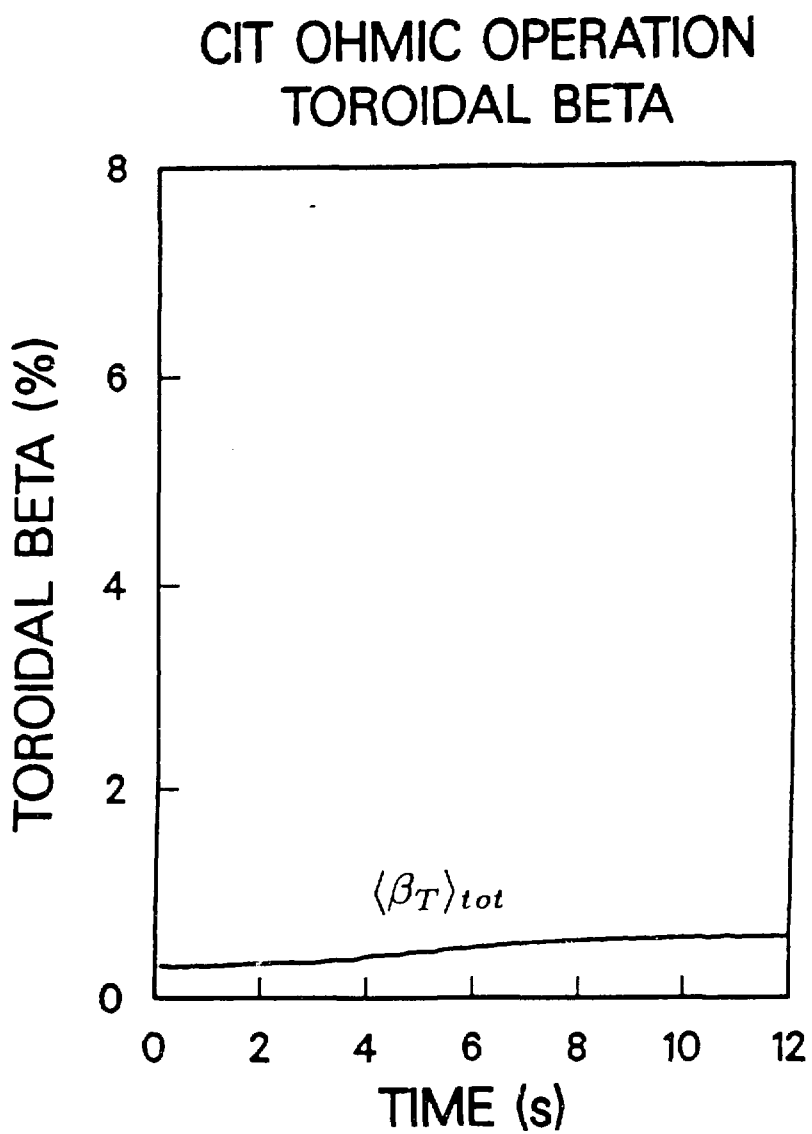
Example cases:

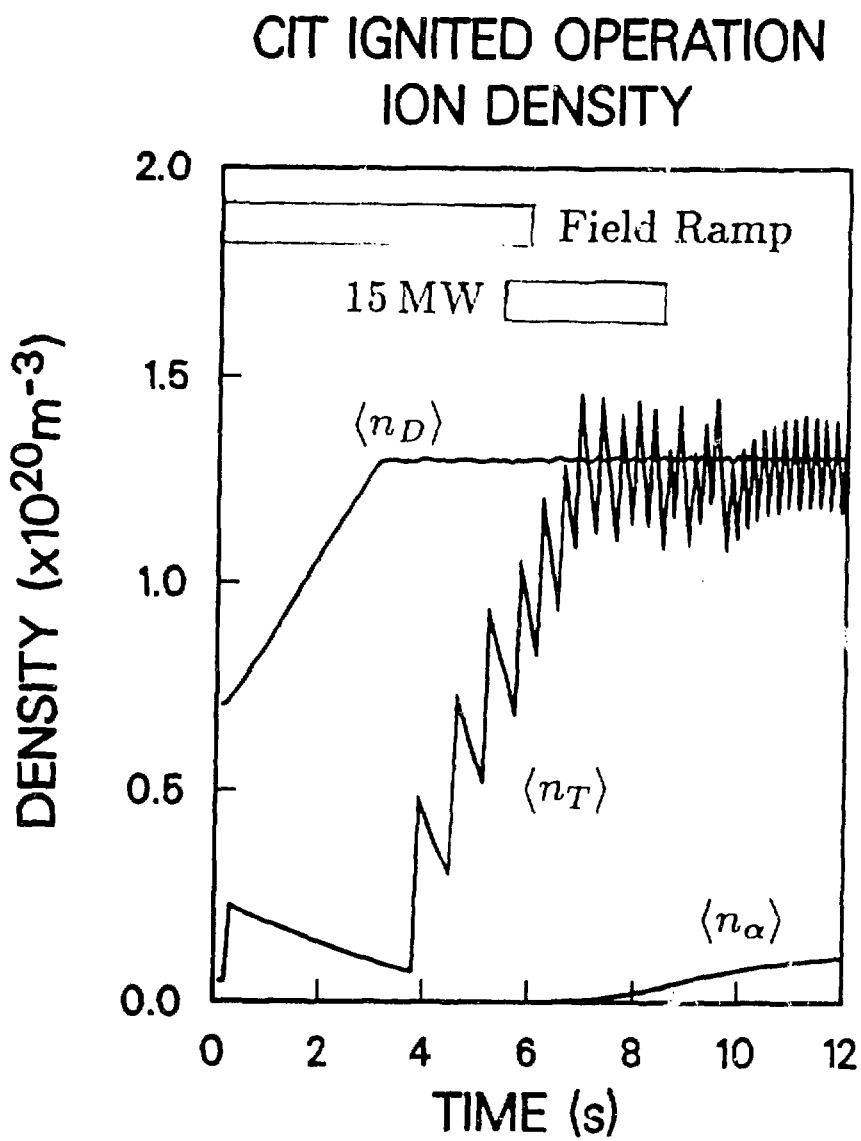
- H-Mode confinement
- D gas and 1.25 mm radius T pellets
- 90% recycle from walls
- Ohmic case: $\Phi_D = 1.9 \times 10^{22}$, $\Phi_T = 0.6 \times 10^{22}$ (12 pellets)
- Ignited case: $\Phi_D = 2.6 \times 10^{22}$, $\Phi_T = 1.6 \times 10^{22}$ (29 pellets)

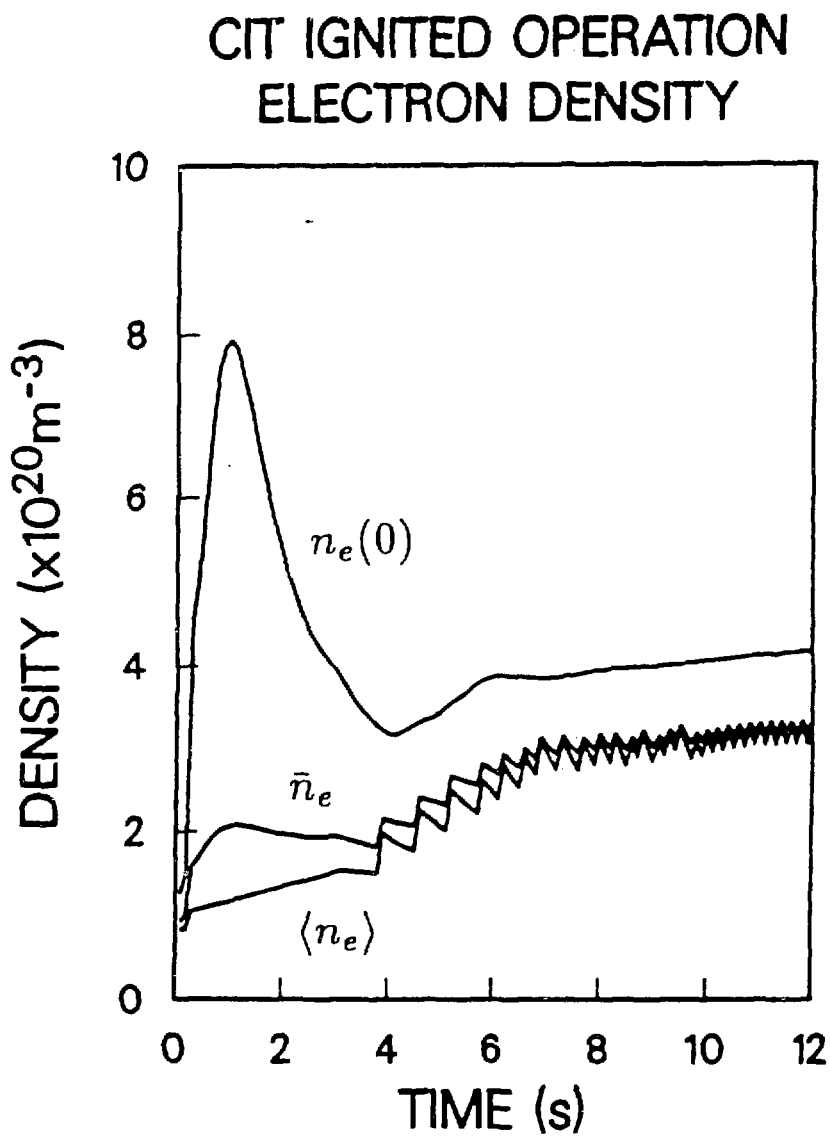

CIT OHMIC OPERATION
ION DENSITY
Field Ramp
$\langle n_D \rangle$
$\langle n_T \rangle$
DENSITY (x10^{20}m^{-3})
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
TIME (s)

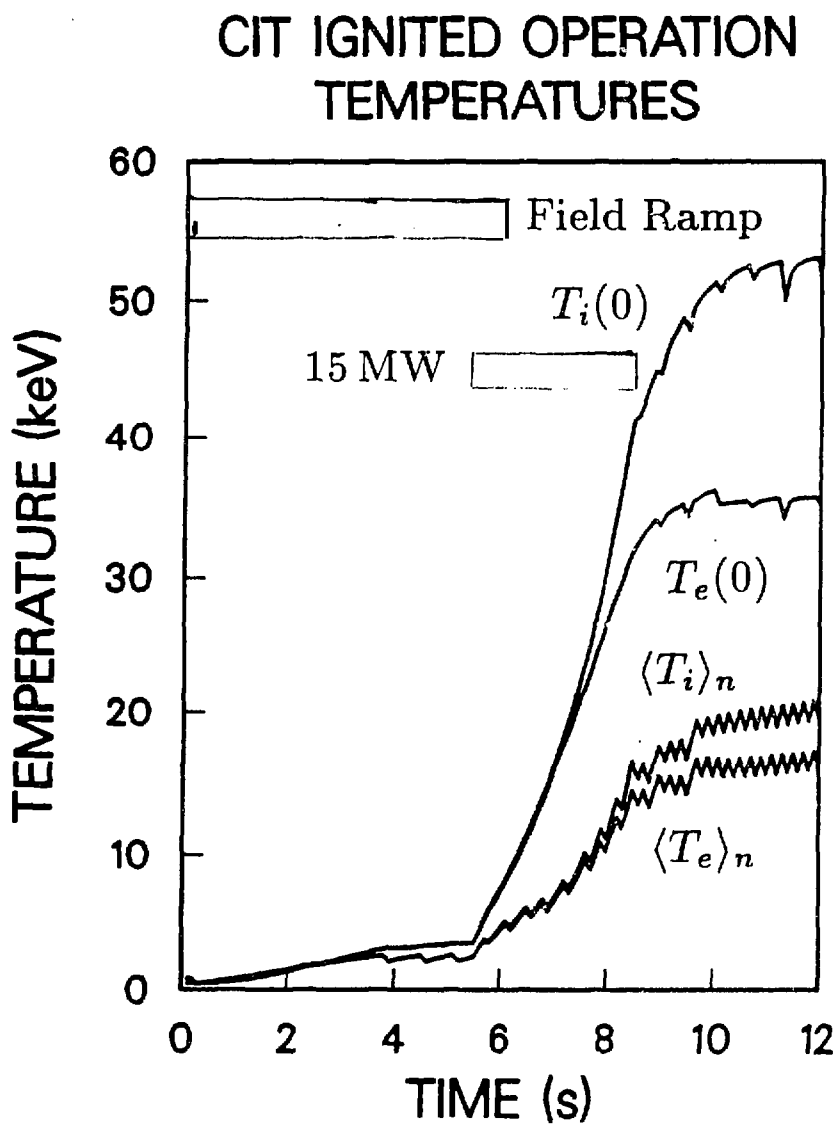

CIT OHMIC OPERATION
ELECTRON DENSITY
$n_e(0)$
$\bar{n}_e$
$\langle n_e \rangle$
DENSITY (x10^{20}m^{-3})
10
8
6
4
2
0
0
2
4
6
8
10
12
TIME (s)

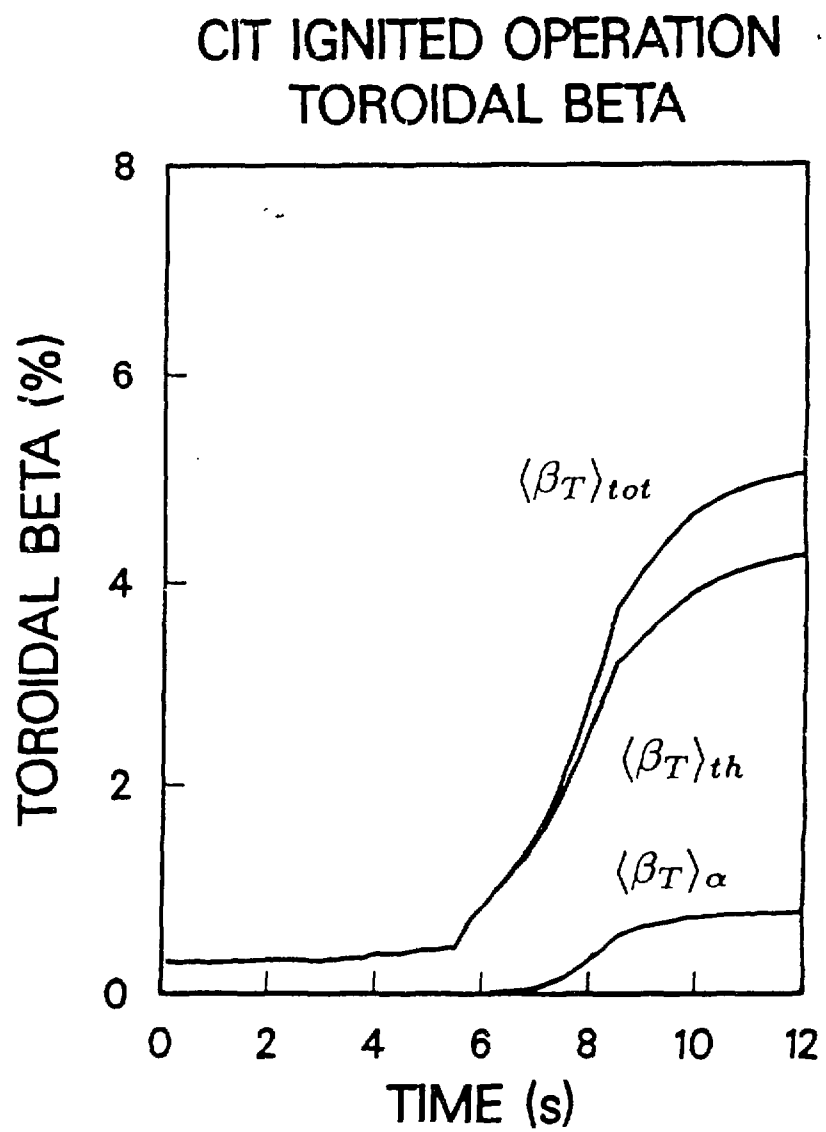

CIT OHMIC OPERATION
TEMPERATURES
TEMPERATURE (keV)
TIME (s)
$T_e(0)$
$T_i(0)$
$\langle T_e \rangle_n$
$\langle T_i \rangle_n$
Field Ramp
0
0.5
1
1.5
2
2.5
3
3.5
0
2
4
6
8
10
12


CIT OHMIC OPERATION
TOROIDAL BETA
TOROIDAL BETA (%)
TIME (s)
$\langle \beta_T \rangle_{tot}$
0
2
4
6
8
0
2
4
6
8
10
12


CIT IGNITED OPERATION
ION DENSITY
Field Ramp
15 MW
$\langle n_D \rangle$
$\langle n_T \rangle$
$\langle n_\alpha \rangle$
DENSITY ($\times 10^{20} m^{-3}$)
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
10
12
TIME (s)


CIT IGNITED OPERATION
ELECTRON DENSITY
$n_e(0)$
$\bar{n}_e$
$\langle n_e \rangle$
DENSITY ($\times 10^{20} m^{-3}$)
10
8
6
4
2
0
0
2
4
6
8
10
12
TIME (s)


CIT IGNITED OPERATION
TEMPERATURES
Field Ramp
15 MW
$T_i(0)$
$T_e(0)$
$\langle T_i \rangle_n$
$\langle T_e \rangle_n$
TEMPERATURE (keV)
TIME (s)
0
10
20
30
40
50
60
0
2
4
6
8
10
12


CIT IGNITED OPERATION
TOROIDAL BETA
$\langle \beta_T \rangle_{tot}$
$\langle \beta_T \rangle_{th}$
$\langle \beta_T \rangle_{\alpha}$
TOROIDAL BETA (%)
TIME (s)
0
2
4
6
8
0
2
4
6
8
10
12

SUMMARY

Pellet injector technology:

- Utilize existing technology for basic injector
- Several options for enhanced velocity injectors are under development

Adequate models exist for pellet ablation

Improvements in confinement models can come from the TFTR and JET programs:

- Scaling of diffusive and pinch terms in particle flux under H- and L-Mode conditions
- Means of sustaining centrally peaked density profiles
- The role of the density profile in energy confinement