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PRODUCTION OF HIGH DENSITY PLASMA BY PELLET INJECTION IN TFTR

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Presented by

S. L. Milora

Oak Ridge National Laboratory *

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ABSTRACT

PRODUCTION OF HIGH DENSITY PLASMA BY PELLET INJECTION IN TFTR

S.L. Milora, G.L. Schmidt, S.K. Combs, Oak Ridge National Laboratory;*
C.E. Bush, R.J. Goldston, B.Grek, R.J. Hawryluk, D.Johnson, D.Mansfield, H.Park, and M.Shimada, Plasma Physics Laboratory, Princeton University

High plasma densities have been produced in ohmic and neutral beam heated discharges on TFTR using a repeating pneumatic pellet injector developed at Oak Ridge National Laboratory (ORNL). Line average plasma densities as high as $1X10^{14}$ cm^{-3} have been attained by injection of five 2.7 mm deuterium pellets $\Delta n_e = 2X10^{14}$ cm^{-3} over a one-second interval into a stetched neutral beam pulse. Injection of a single large (4 mm) pellet in ohmic discharge has produced highly peaked profiles with nec(o) = $1.8X10^{14}$ cm^{-3}, $n_e(0)$ $\tau_E(a) = 6.7X10^{13}$ cm^{-3} and $n_D(0)Ti(0)\tau_E(a) = 8.8X10^{13}$ cm^{-3} sKev. Global confinement in these discharges approaches 0.45 seconds with a central density decay time of 2 seconds. Based on a neoclassical resistivity model and X-ray pulse-height analysis, zeff is <2 in both ohmic and beam-heated plasmas.

The energy confinement properties of intermediate density $\left(n_e(0) = 1X10^{14}\text{ cm}^{-3}\right)$ full beam power (5.7 MW, 8C KVD°) discharge have been studied in detail using the TRANSP code. The high density pellet-fueled plasmas are contrasted with gas fueled cases by a strongly im?ted beam power deposition profile. Although the global energy confinement (≈2 oums at IP = 2.2 MA) is comparable to gas-fueled discharges, the confinement in the central core is considerably longer and electron heat conduction loses are smaller.

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SUMMARY OF RESULTS

- Initial (not definitive!) experiments with pellet injection on TFTR conducted in the March 19 through April 12 run period:

  $$1.4 < I_p < 2.2 \text{ MA}$$

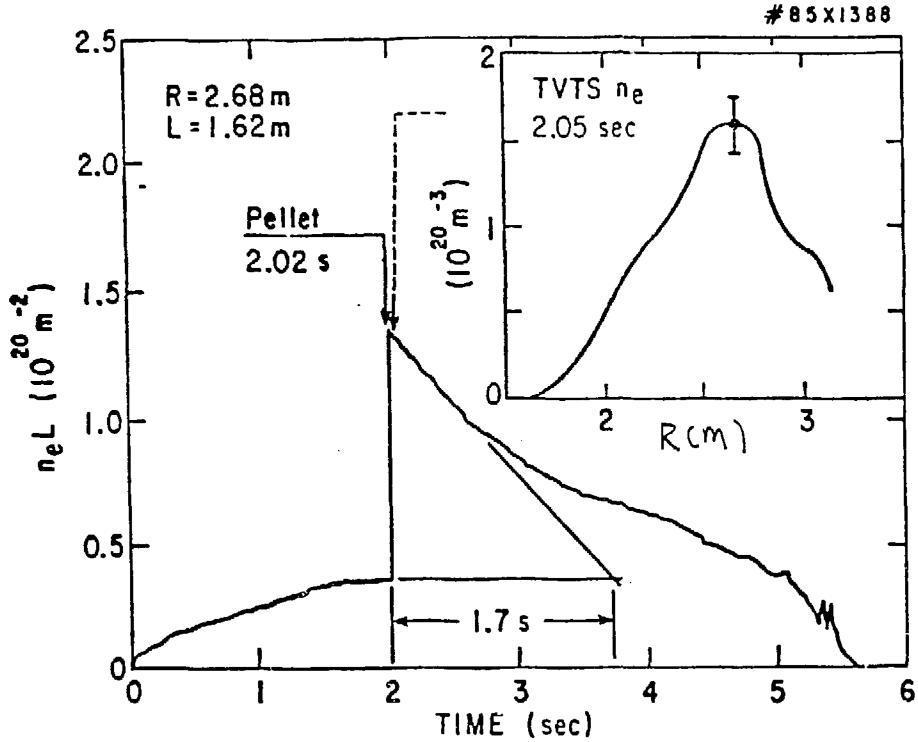
  $$4 < B_t < 4.8 \text{ T}$$

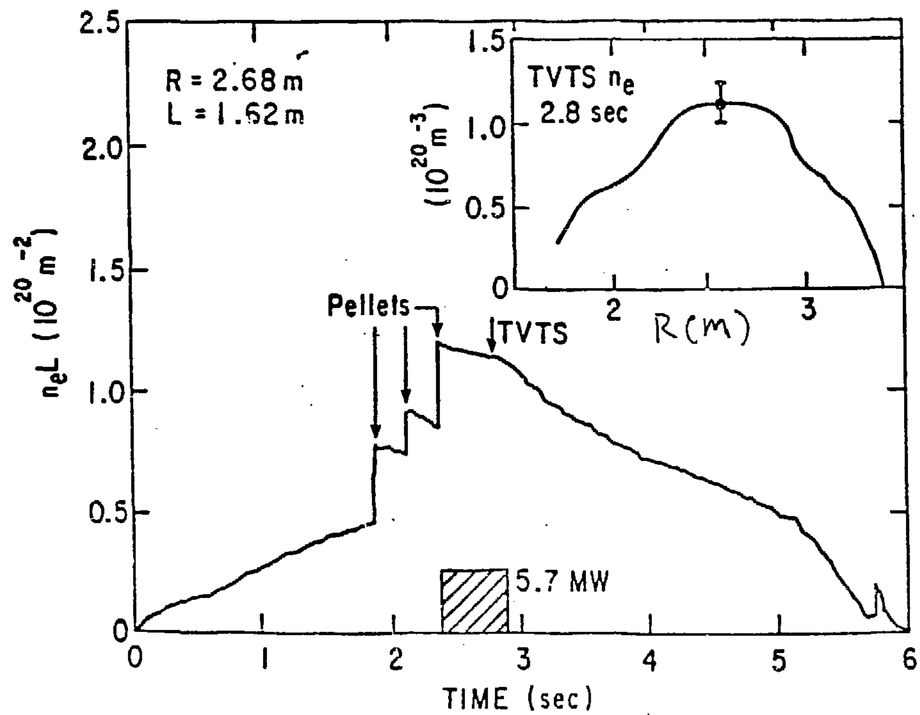
  $$3.2 < P_{inj} < 5.7 \text{ MW}$$

- ORNL Repeating Pneumatic Injector operating in two configurations:
  - Single 4 mm pellet ($2.1 \times 10^{21} D^\circ$) at 1400 m/s giving central penetration
  - Multiple 2.7 mm pellets ($7 \times 10^{20} D^\circ$) at 1250 m/s and 4 /s giving: 40 - 50 cm penetration ($\approx a/2$)

- Large "horse pill" pellet results (ohmic only):
  - $n_e(o) = 1.8 \times 10^{14}$ cm^{-3}; Murakami parameter > 5
  - "τ_p" $\approx$ 2 s
  - τ_E = 0.45 (comparable to high density H_e discharges)
  - $n_D(o)\tau = 6.8 \times 10^{13}$ cm^{-3} s

- Multiple small pellet injection (with NBI):
  - $\bar{n}_e = 10^{14}$ cm^{-3}
  - τ_E = 200 - 250 ms (comparable to gas puffing)
  - High central confinement => profile consistency, heat pinch arguments





Single large pellet and multiple small pellet experiments were performed

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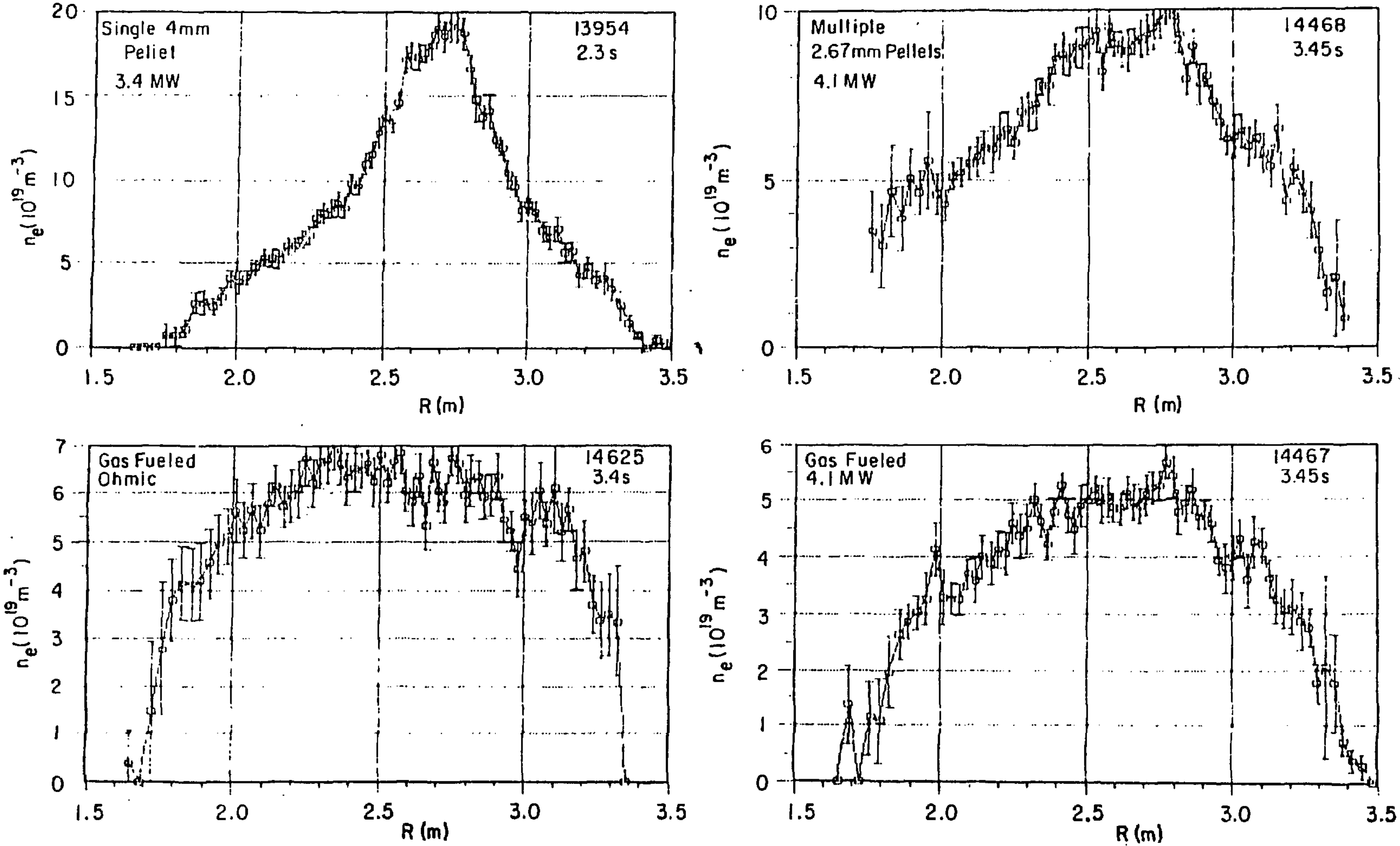
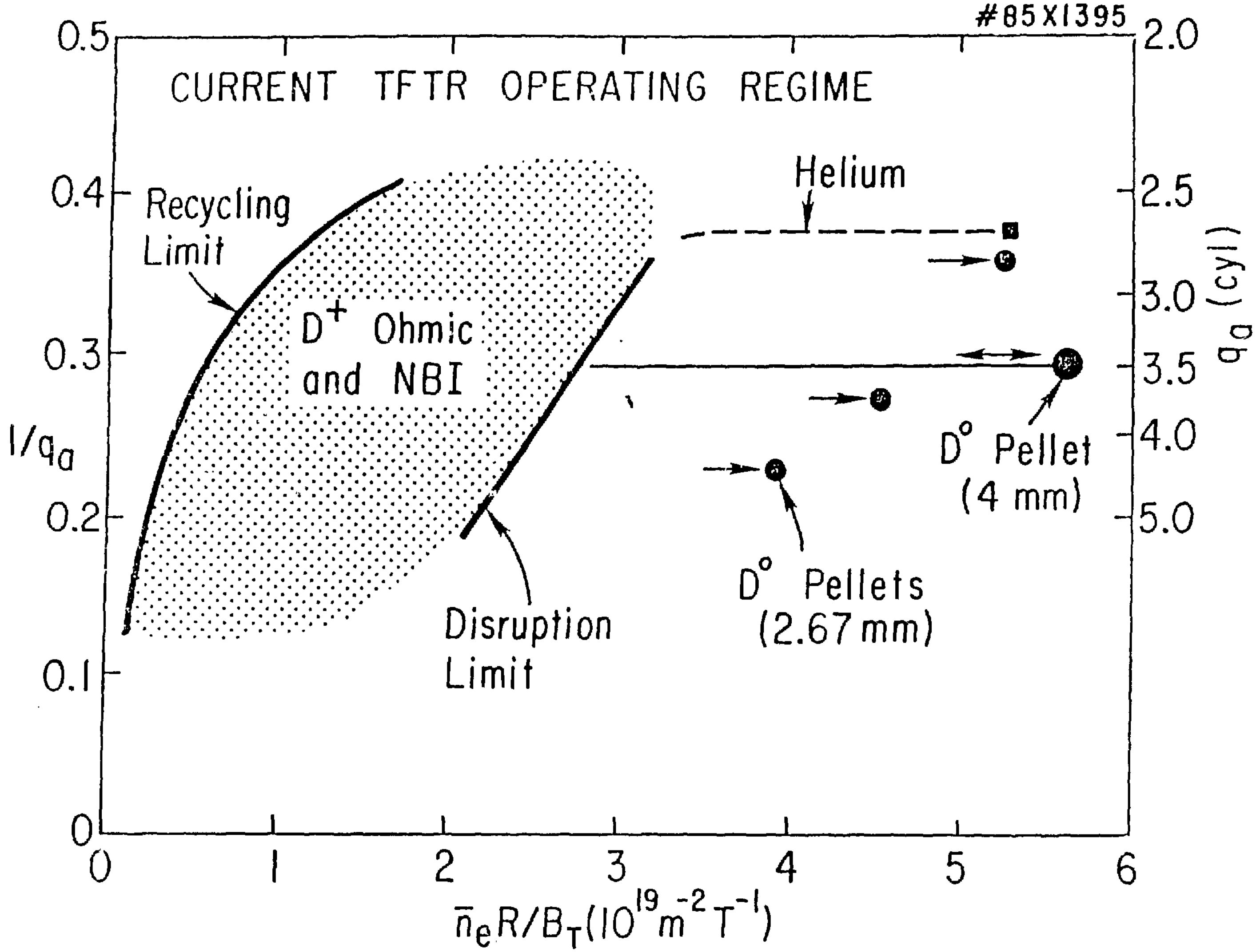


Pellet injection produces higher densities and more centrally peaked profiles than gas puffing.



Pellet fueling extends operating regime in deuterium by ~a factor of two in ohmic and beam heated discharges.

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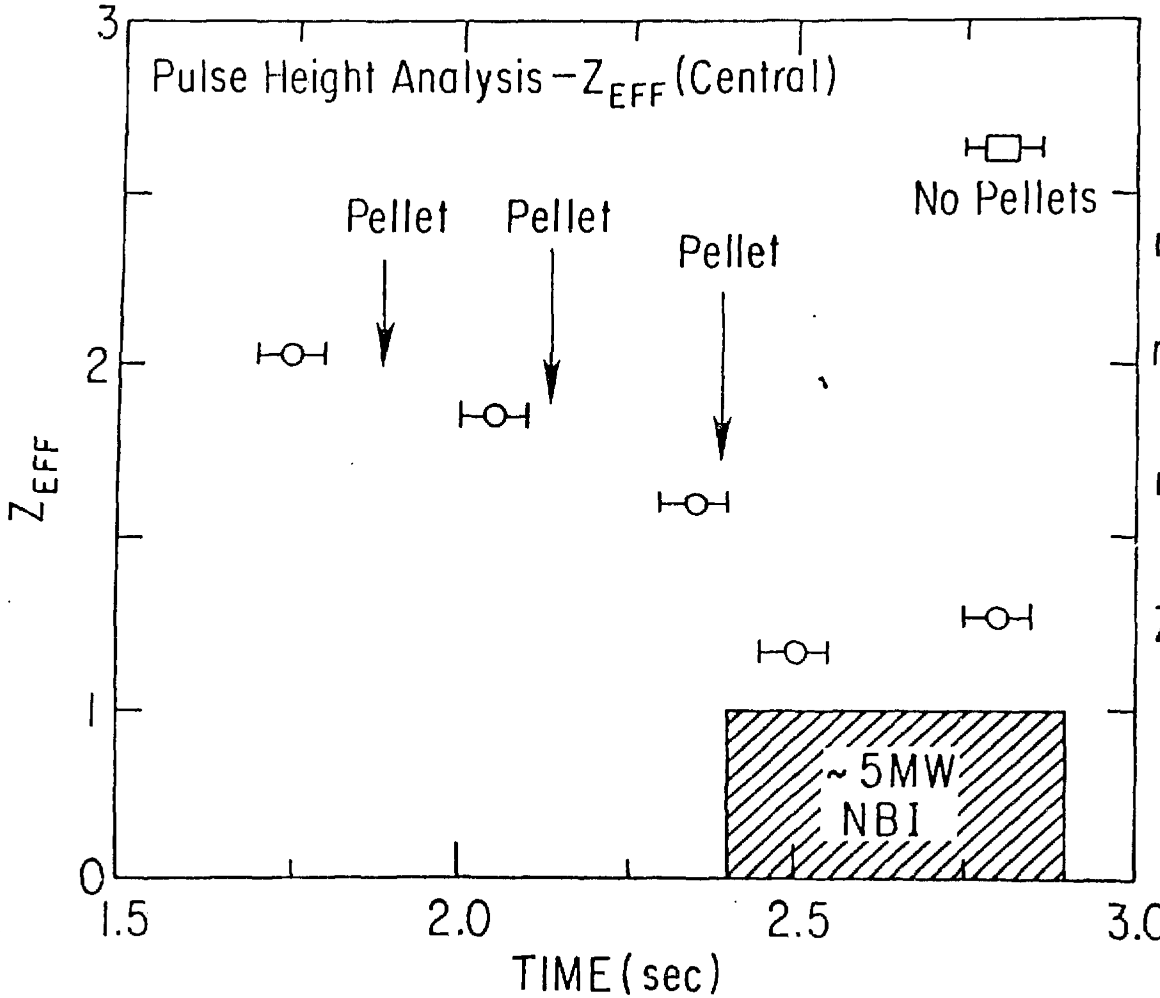
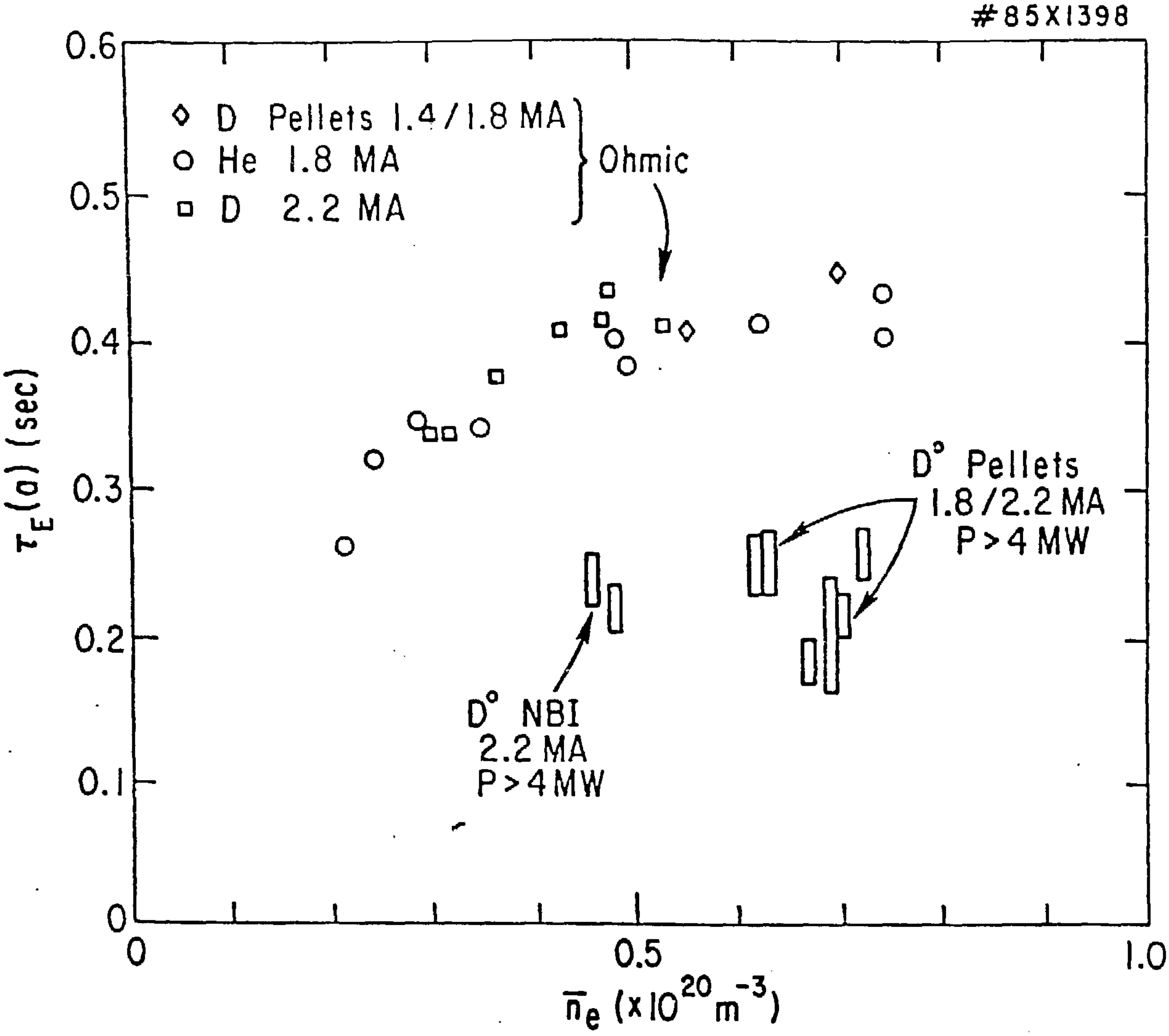
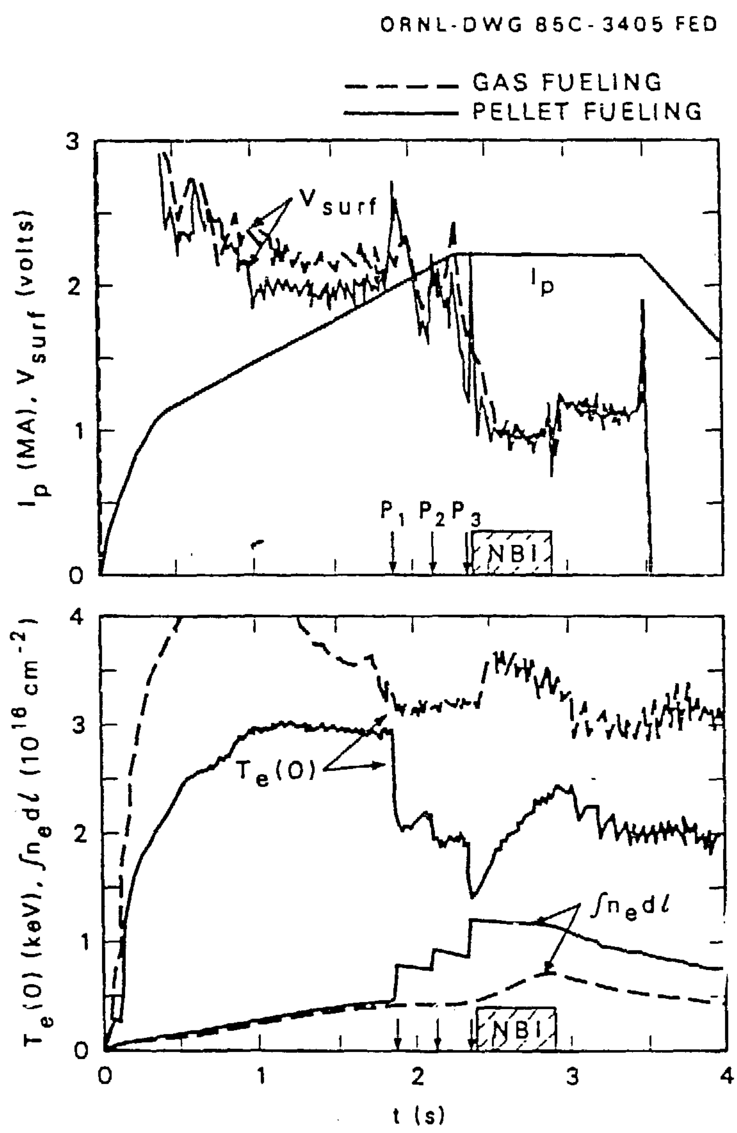


	2.8 sec	
	Pellets	No Pellets
n_e	10	$5.7 \times 10^{19} m^{-3}$
n_{Ni}	0.3	$2 \times 10^{16} m^{-3}$
n_{C+O}	0.6	$1.9 \times 10^{18} m^{-3}$
Z_{EFF}^{METAL}	0.03	0.37

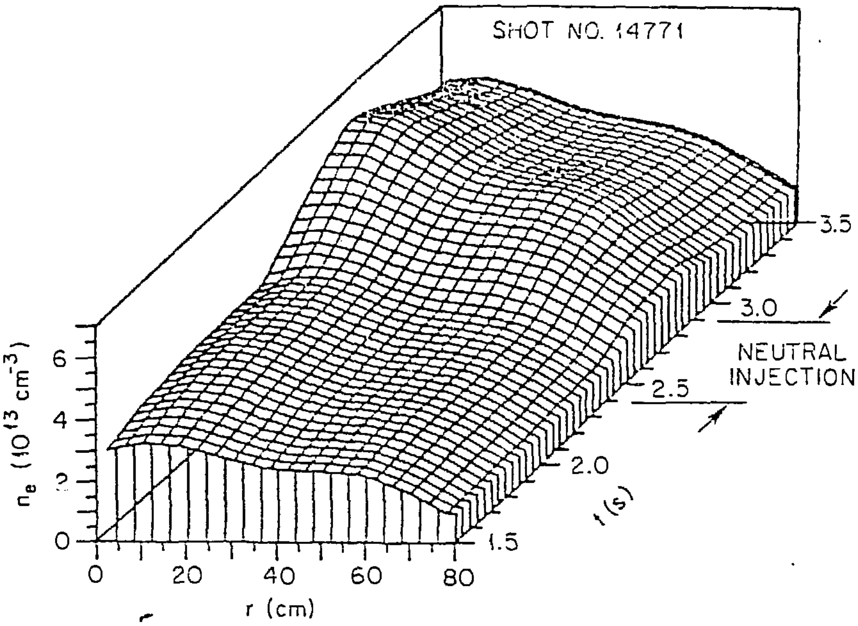
Zeff decreases after pellet injection. Metals are reduced by a factor of 10.

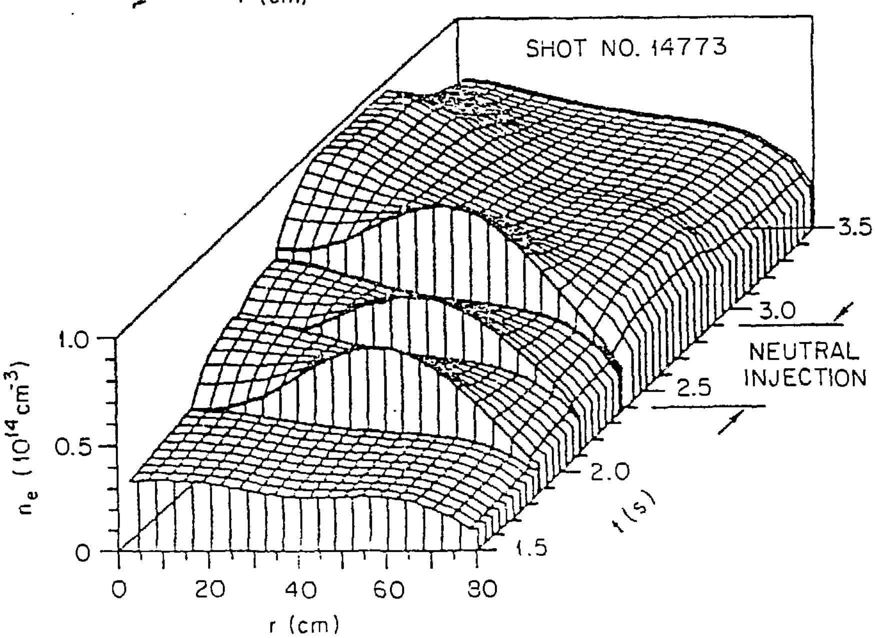


Confinement summary in ohmic and beam-heated discharges

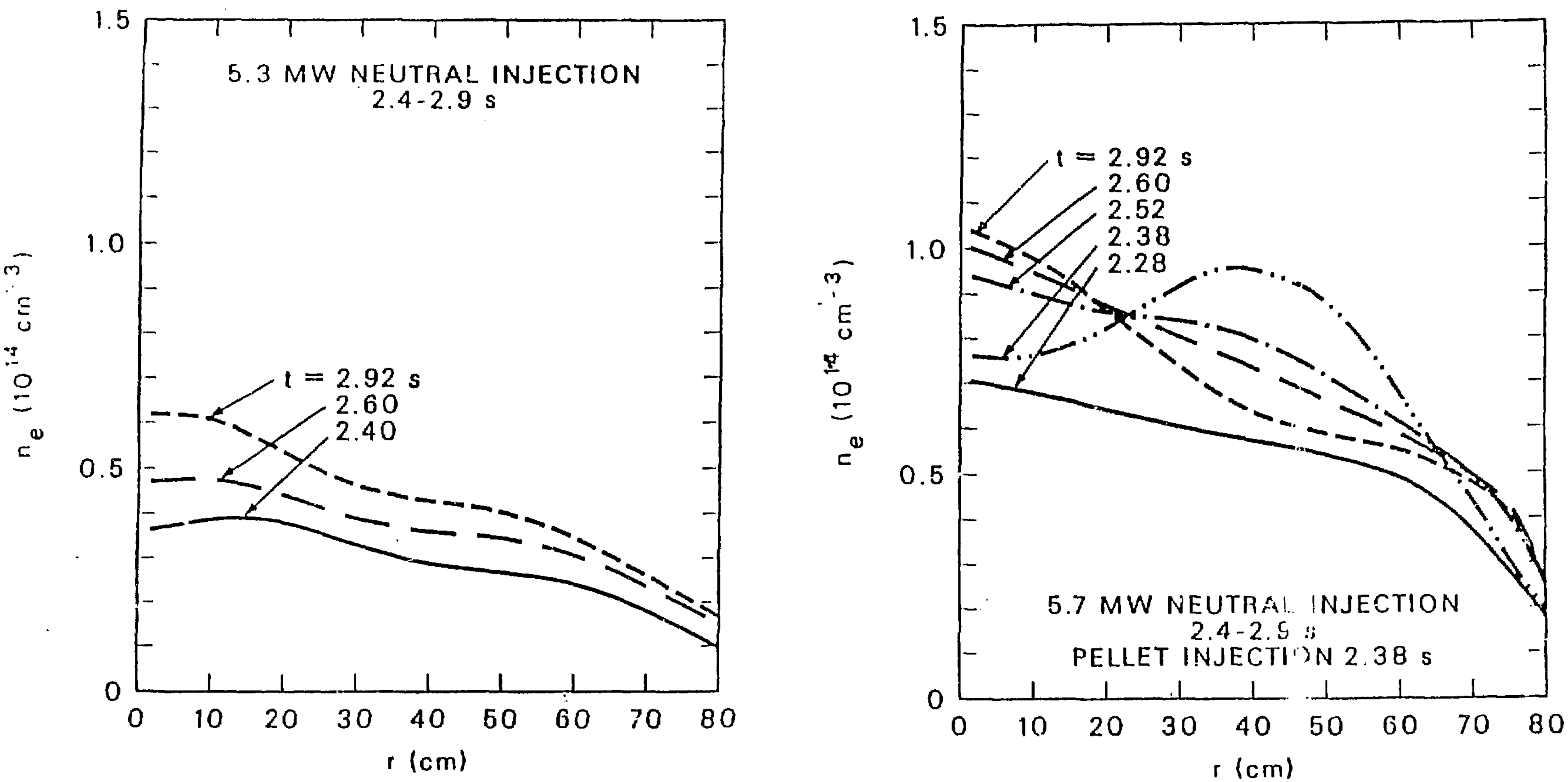


Comparison of gas fueled and 3 pellet discharges with 5.7MW, 0.5s neutral beam heating.



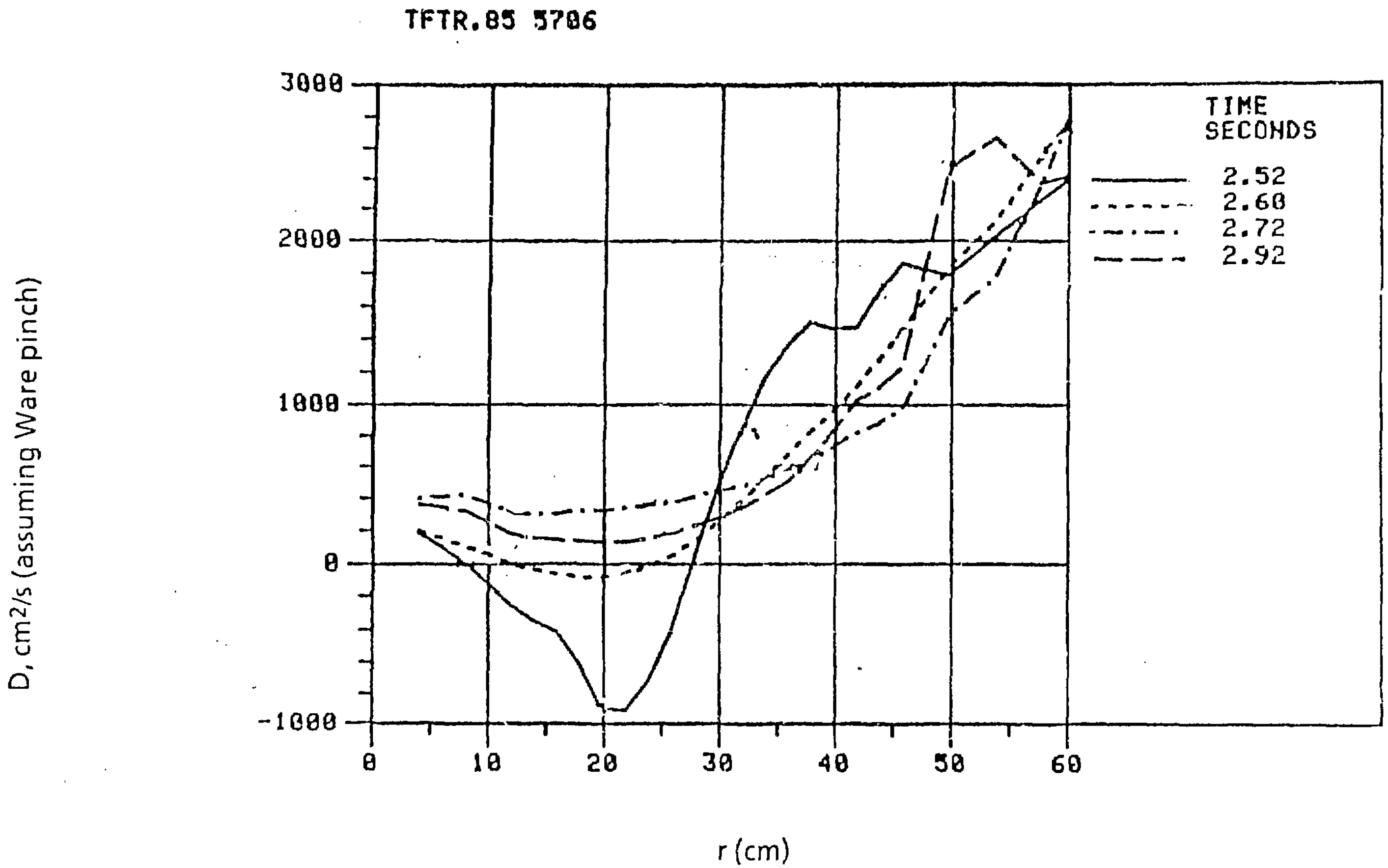


In low density gas puffing discharges, beam fueling is significant. Pellets penetrating to the half radius produce inverted profiles that relax in ≈100ms. Peaking of the profile suggests inward pinch. Beam fueling in pellet discharges appears to be localized at the edge.

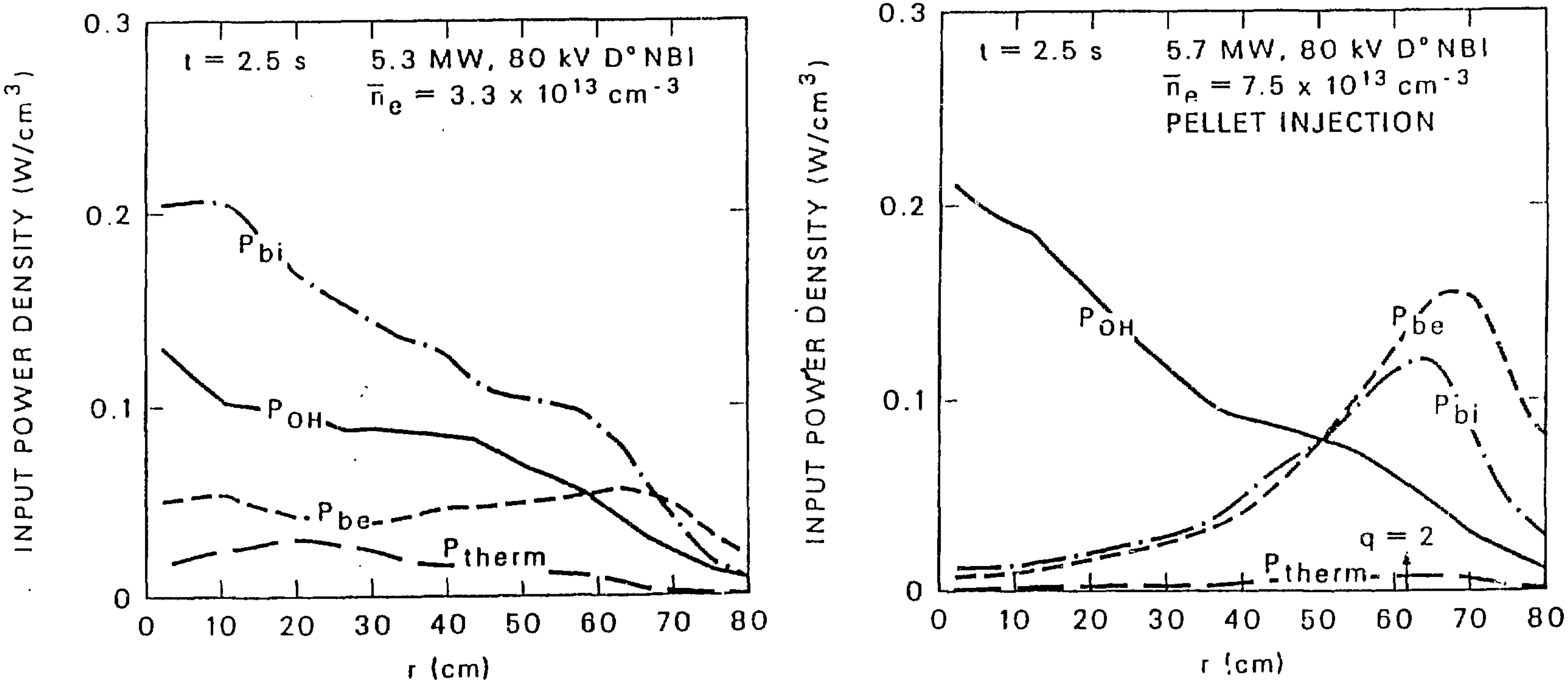


Density profile increases as a result of beam fueling in gas puffing case $\left(\frac{dN}{dt} > 0 \right)$.

Profile peaks after pellet injection while $\frac{dN}{dt} < 0$.



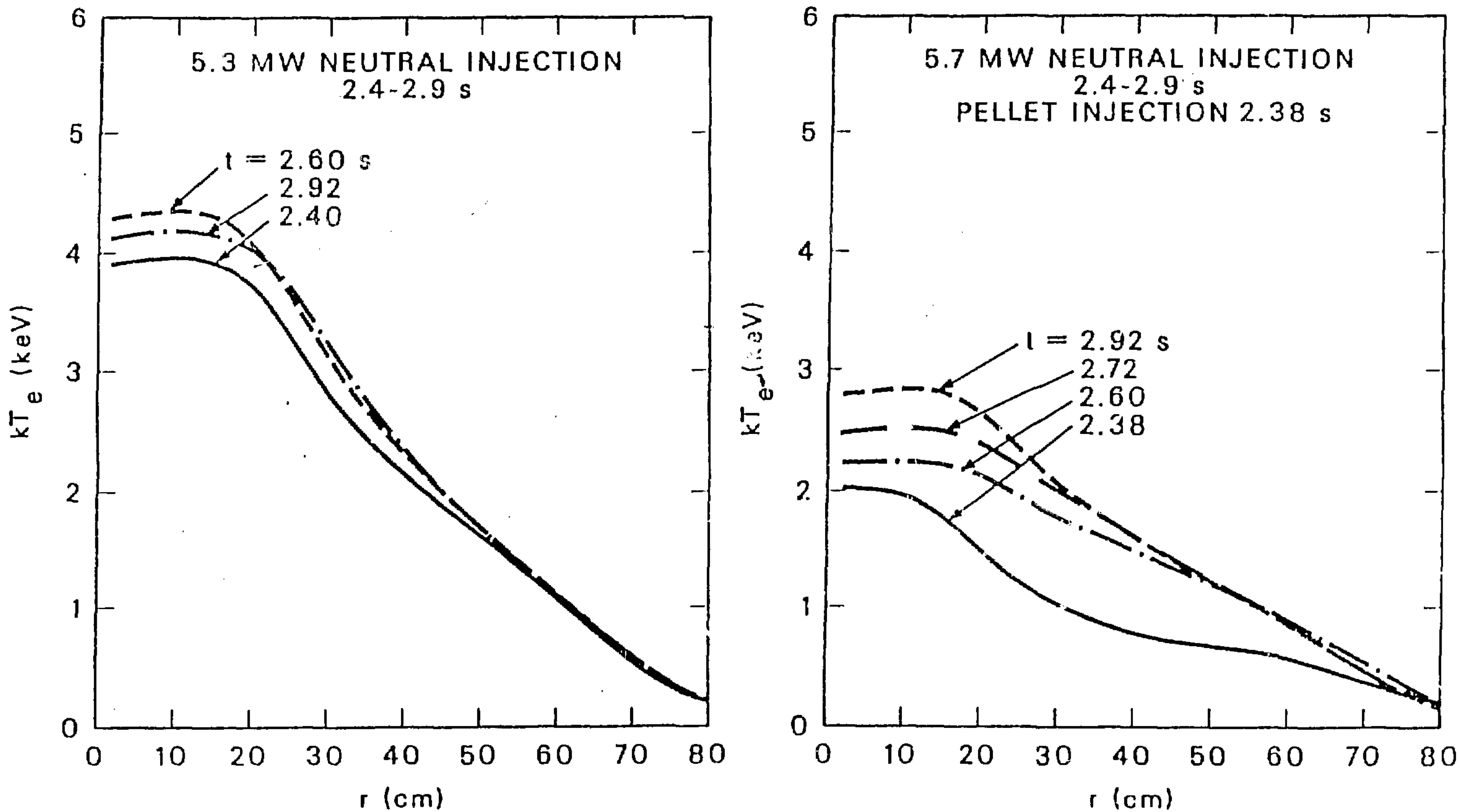
Inward velocities on the order of or greater than the Ware pinch are required to explain the density peaking.



Input power density for low density gas injection case is centrally peaked with $P_{bi} > P_{OH} > P_{be} > P$ therm.

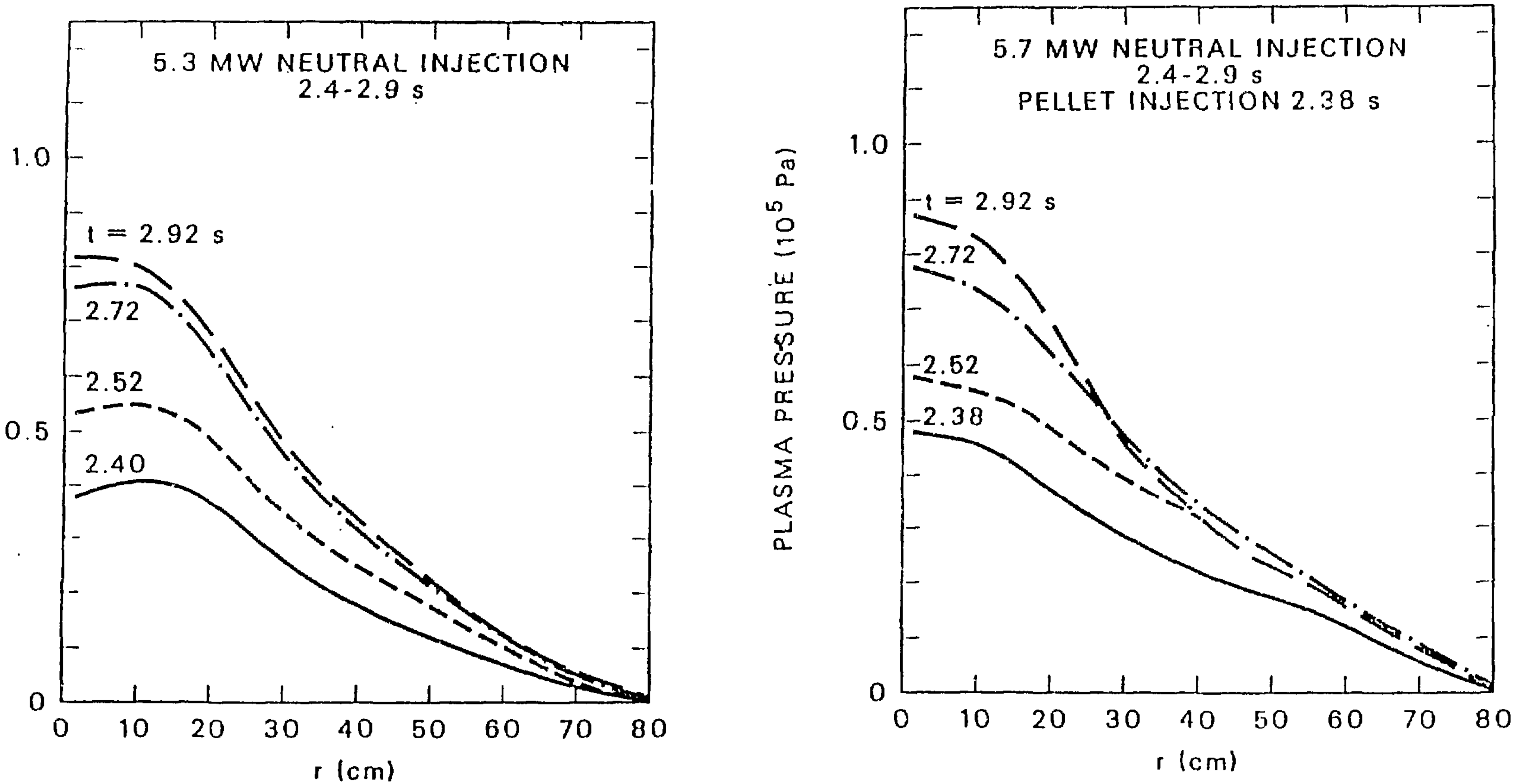
Inverted profiles are calculated for pellet injection example. Ohmic heating dominates inside 40cm. More than half the total power is deposited outside $q = 2$ surface.

Power deposited inside a given radius is smaller for pellet case (but total power inside $r = a$ is the same).



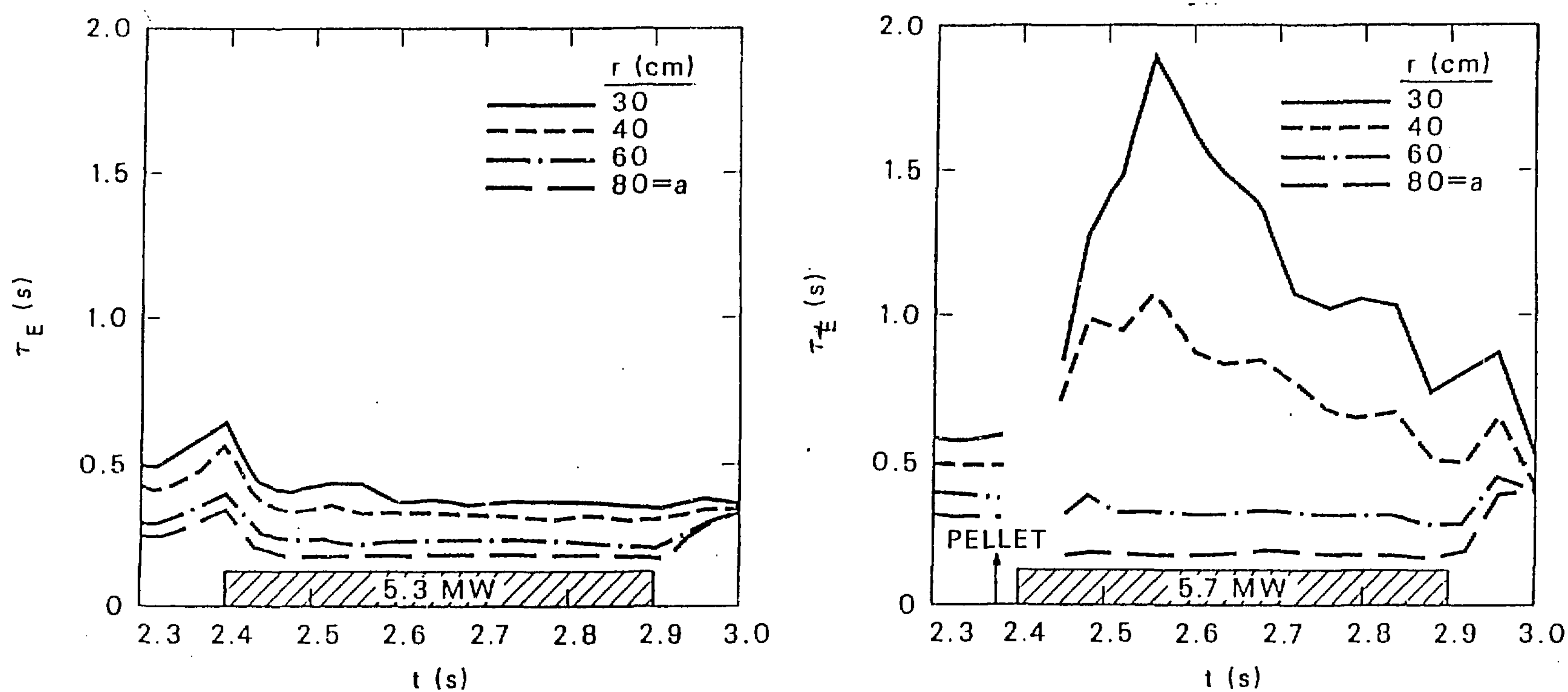
For gas fueling the electron temperature profile increases at first and then decreases later in the beam pulse due to increasing density (beam fueling).

For pellet fueling the edge temperature increases rapidly as a result of strong beam heating. The central temperature increases continuously.



Plasma pressure profiles are similar through the beam pulse. Edge pressure in the pellet case evolves more rapidly.

Total plasma energy inside a given radius is comparable for both cases.



Since total plasma energy and total input power is the same, global confinement is similar (200ms; $I_p/10$) during beam pulse.

For pellet injection, internal confinement time is substantially higher but decays in time.

"CONVENTIONAL" ANALYSIS PROCEDURE (TRANSP)

- Measured: $n_e(r, t)$, $T_E(r, t)$, I_p, V surface, $P_{rad}(r, t)$

- Solve poloidal magnetic field diffusion equation with $\eta = \eta_{neo}$ and measured V surface for:

$$Z_{eff}(t), \ P_{OH}(r, t)$$

- Solve particle conservation equation with $\tau p = .2$ s assumed and models for beam- and wall-generated neutral sources for:

$$\vec{\Gamma}(r, t); \ P_{conv} = \vec{\nabla} \cdot \left(\frac{5}{2} \vec{\Gamma} T\right)$$

- Solve ion energy balance equation assuming K_i = multiplier X neoclassical for:

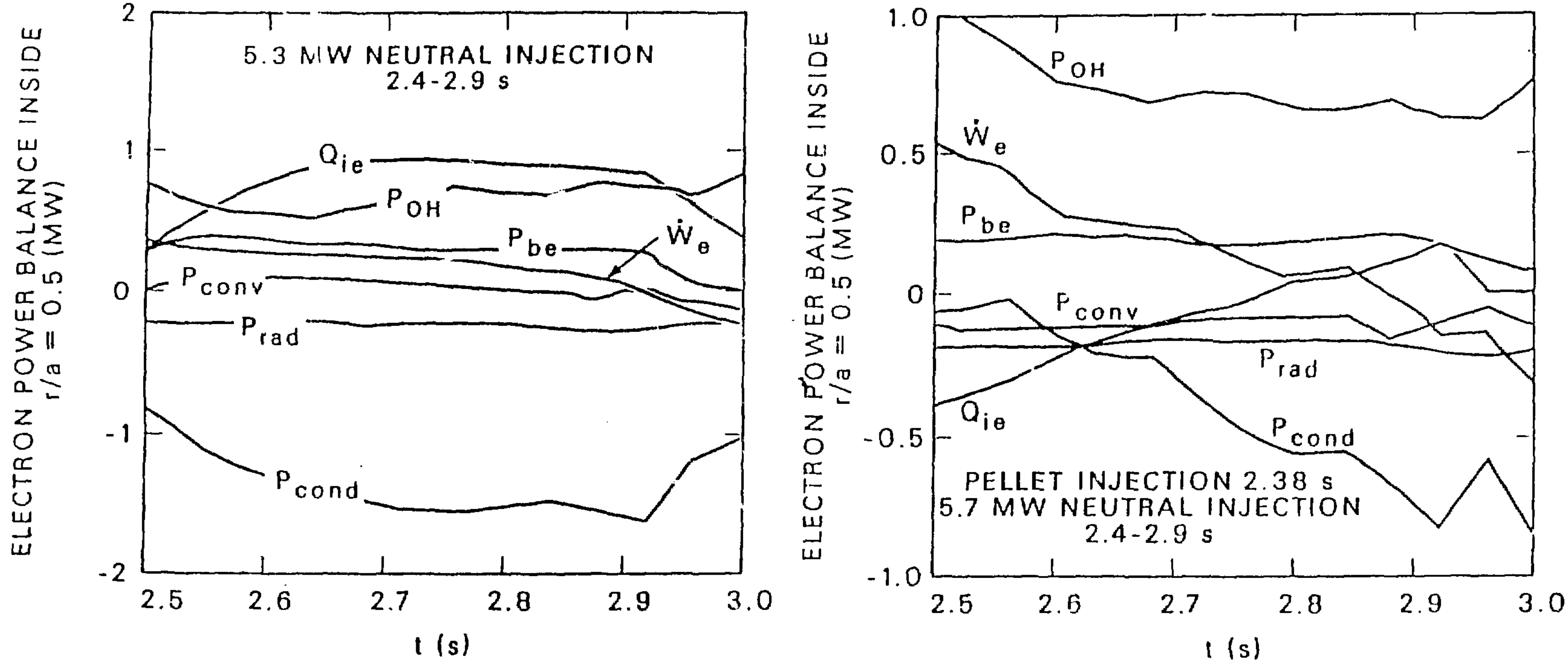
$$Ti(r,t) \text{ and } Q_{ie}(r,t)$$

- Solve election energy balance equation for electron heat conduction loss:

$$P_{cond} = P_{OH} + P_{be} - Q_{ie} - P_{rad} - P_{conv} - \dot{W}_e \ \text{(reheat)}$$

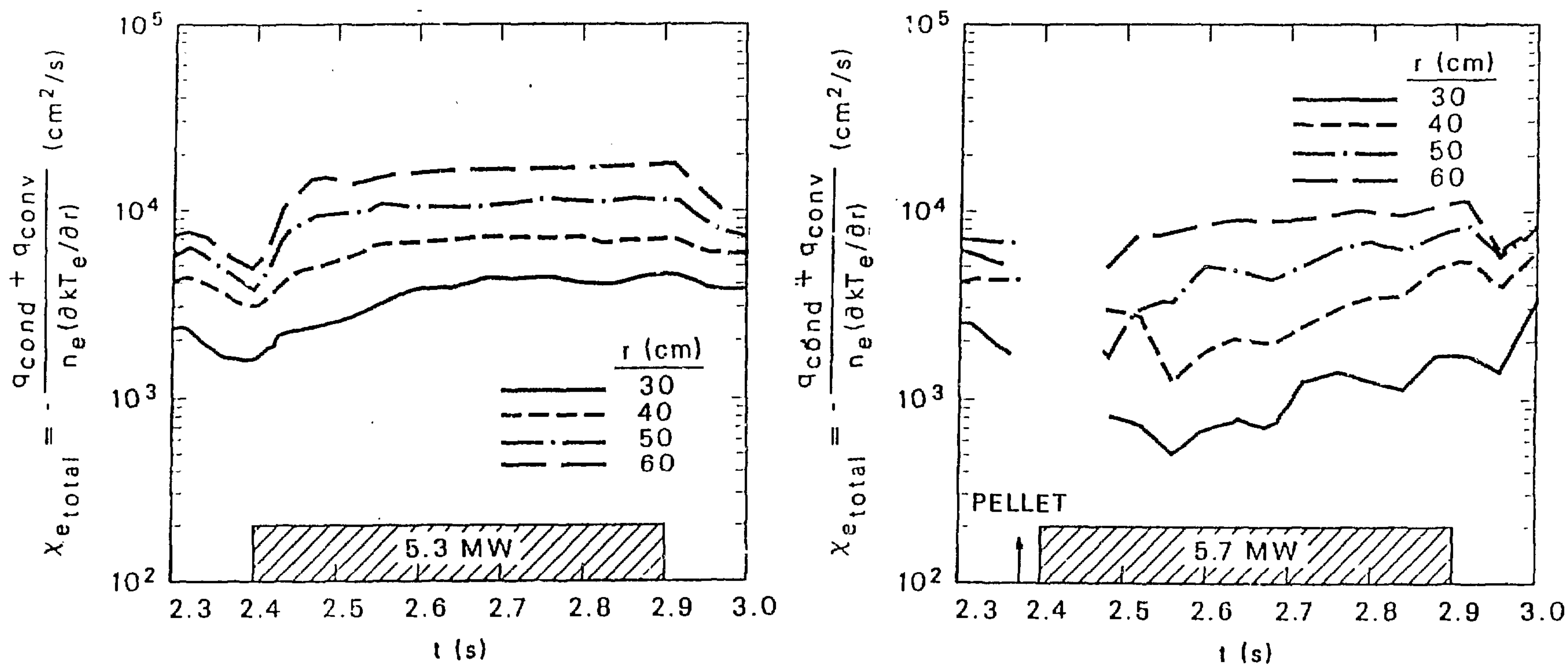
Constraint:

$$P_{cond} > 0 \text{ when } \frac{\partial Te}{\partial r} < 0$$

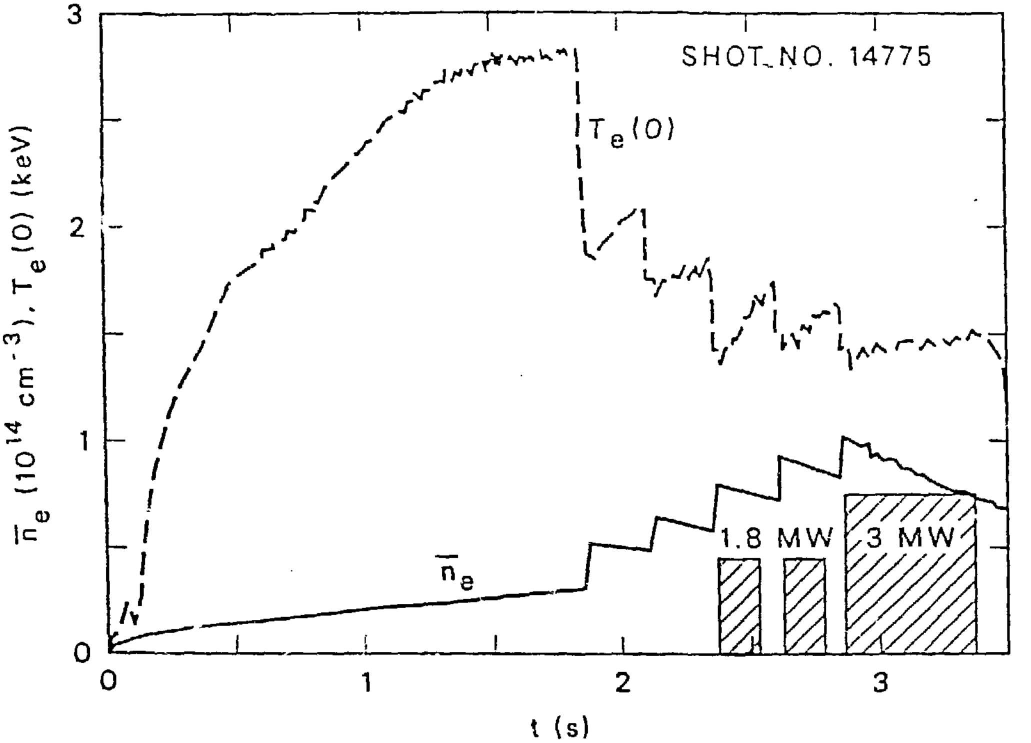


For low density gas puffing case inside r = 40cm, ions heat electrons - $Q_{ie} > P_{OH} > P_{be}$. Convection is negligible. Conduction dominates. Ki = 3x Chang-Hinton.

For pellet fueling, electrons heat ions - P_{OH} is dominant input power. Prad is similar to gas fueling. Convection is small. Conduction is much smaller than gas puffing case. To satisfy Pcond <0 early in time, Q_{ie} must be minimized by taking Ki = 1X Chang-Hinton.

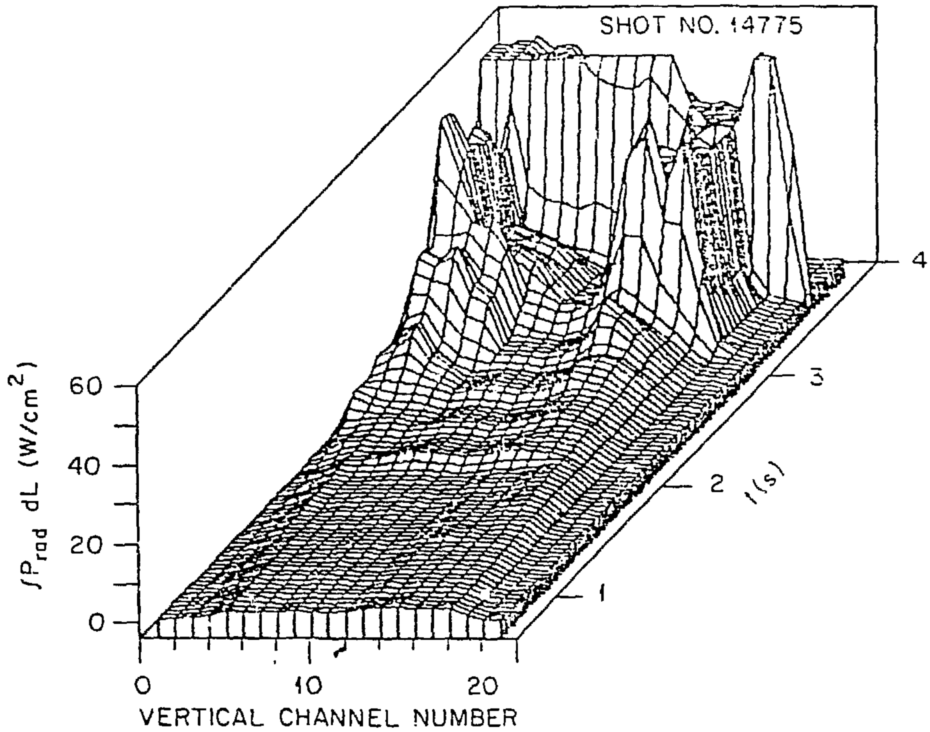


Total electron thermal conductivity (including convection term) increases during beam heating with gas puffing and decreases for pellet fueling. By including convection term, is overestimated for pellet injection and underestimated for gas puffing.



To further explore transient confinement improvement, two additional pellets were injected into extended pulse (1 second) reduced power beam.

Recovery of $T_e(0)$ was limited by MARFEs and Prad = Pinput after final pellet.



- Raw bolometer data; vertical array
- Prad = Pin; high edge n_e.
- Future plans:
  - Increase beam power to 6MW.
  - Attempt to reduce edge density by surface pumping.

CONCLUSIONS

- In high density pellet-fueled discharges, beam penetration is poor and heating profile is hollow. Although we expect global confinement to decrease under these circumstances, it is no worse than lower density gas-fueled cases with centrally peaked power deposition.

- A resourceful tokamak plasma compensates for poor beam penetration by cutting back on electron heat conduction losses inside the boundary layer.

  χ_e decreases during NBI reaching values comparable to κ_i^{neo} for about 300 ms

- Global confinement appears to be unaffected by even drastic changes in heating profile shape.