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CONF-8510266--4.

RESULTS OF PELLET INJECTION INTO ISX-B

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CONF-8510266--6
DE86 014236

MASTER

Improvements in plasma performance with pellet injection have been achieved in several tokamaks in recent experiments. On the Impurity Study Experiment (ISX-B), an increase in plasma energy by as much as 50 percent, has been observed following pellet injection. With 1.5-mm pellets, the value for τ_E^*, the gross energy confinement time determined from β_{equil}, has peaked at 1.7 times ISX-B scaling for $n_e = 6 \times 10^{13}$ cm^{-3} in both well-gettered and ungettered discharges. Following the peak, in the well-gettered shots τ_E^* decays to 1.2 times ISX-B scaling within 50 ms after pellet injection. In the ungettered discharges τ_E^* follows the Z-mode scaling that is appropriate to the plasma conditions (P_b = 1.7 MW, I_p = 180 kA). Thus, pellet injection in ISX-B shows energy confinement better than that for gas puffing in clean discharges and matches the Z-mode improvement obtained in ungettered discharges. Confinement improvement following pellet injection has also been achieved in smaller (a_p = 20 cm) plasmas with 1.0 mm diameter pellets. Comparisons of pellet shots which do show this improvement against pellet shots which do not show it are presented.

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IMPROVED PERFORMANCE (P-MODE) OBSERVED FOLLOWING INJECTION OF:

- Large (1.5 mm diam.) H2 pellets into gettered and ungettered ISX-B standard plasmas
  ($a_p = 25$ cm, $I_p = 180$ kA, $P_B = 0.8\text{-}1.7$ MW)

- Small (1.0 mm diam.) pellets into smaller ISX-B plasmas
  ($a_p = 20$ cm, $I_p = 120$ kA, $P_B = 0.8$ MW)
  Not on all shots with pellets on a given day, however

- Small (1.0 mm diam.) pellets into standard discharges at low beam power (few shots)

SIMILARITIES BETWEEN P-MODE AND:

- Z-mode (global confinement scales with density in ungettered plasmas)

- R-mode (transition from ISX-B scaling to 1.8 x ISX-B scaling by running small plasma at larger R)

"P-MODE" IS DISTINCT FROM THESE

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GENERAL FEATURES OF "P-MODE" SHOTS

- Secondary density maximum with time on FIR (all chords) following pellet injection (the density increment "sticks"); drop in H_α near principle limiter (inner rail or top mushroom)

- Change in plasma MHD from sawteeth or bursts of $m = 1$ oscillations before pellet to continuous (large scale $m \neq 1$ oscillations) 20 - 30 ms after pellet

- Increase in β_{equil} and $\beta_{diamagnetic}$

- Apparent current profile transient (changes in internal inductance, position, V_{loop}; abrupt termination of pre-pellet MHD)

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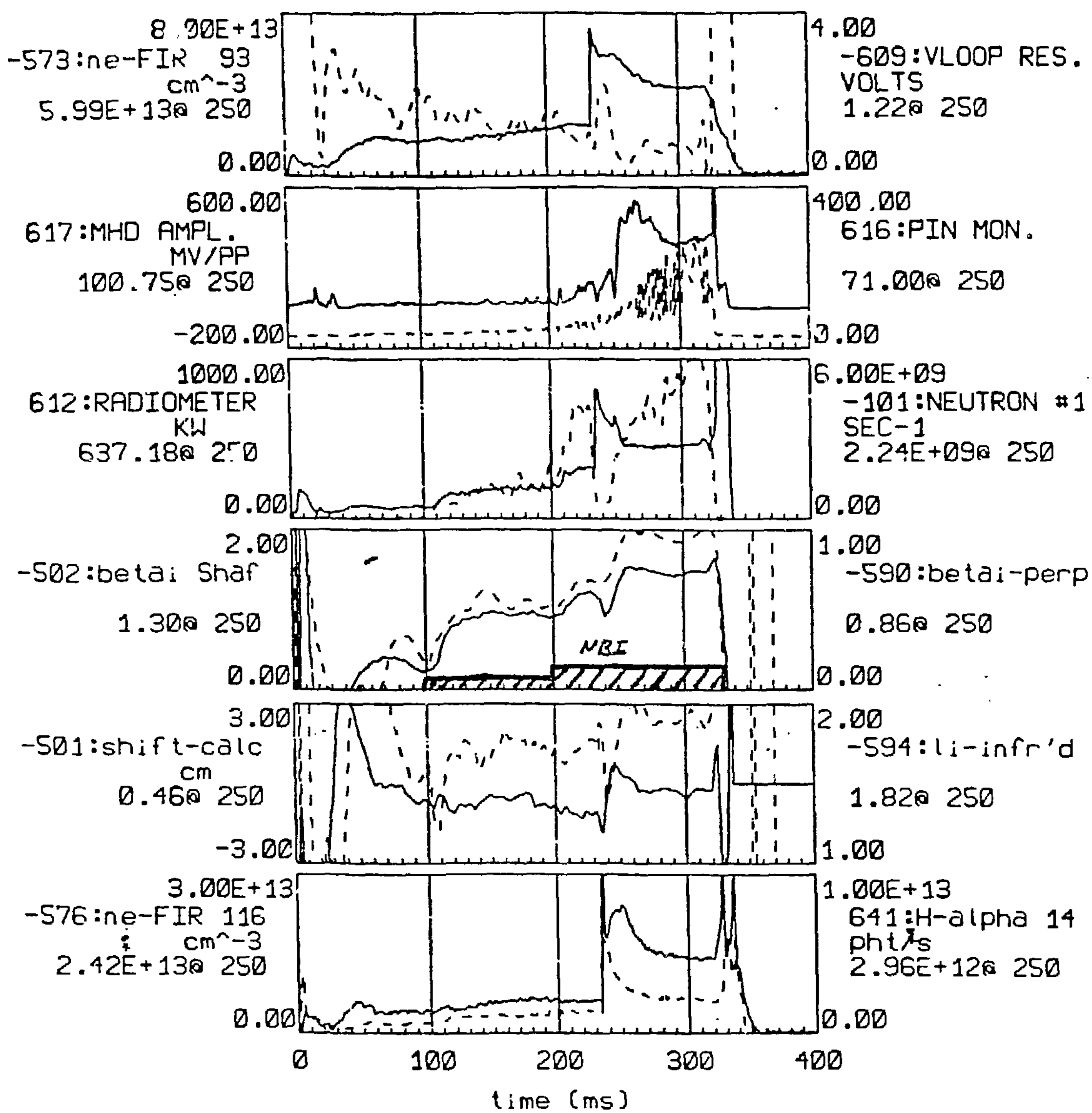
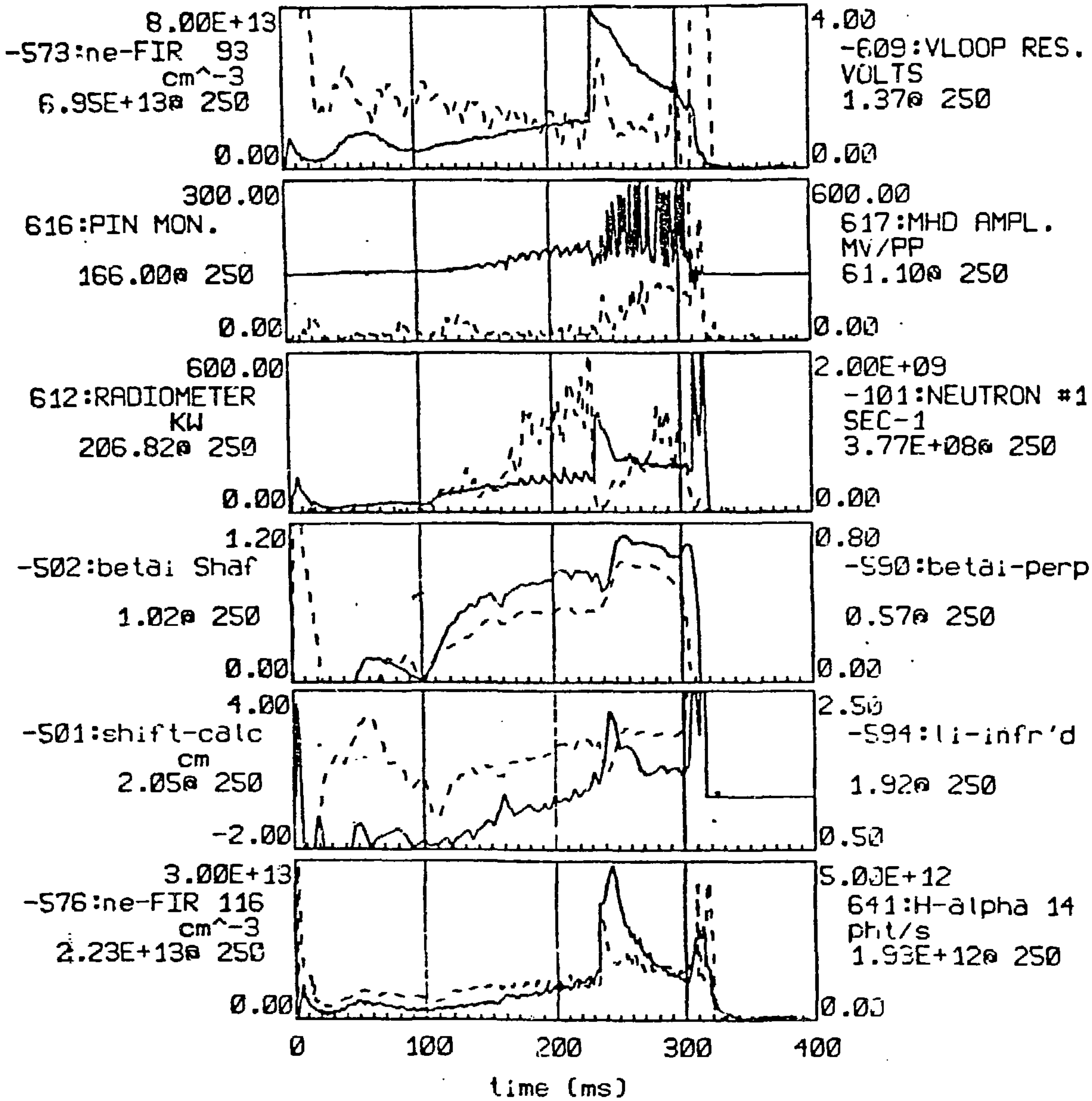
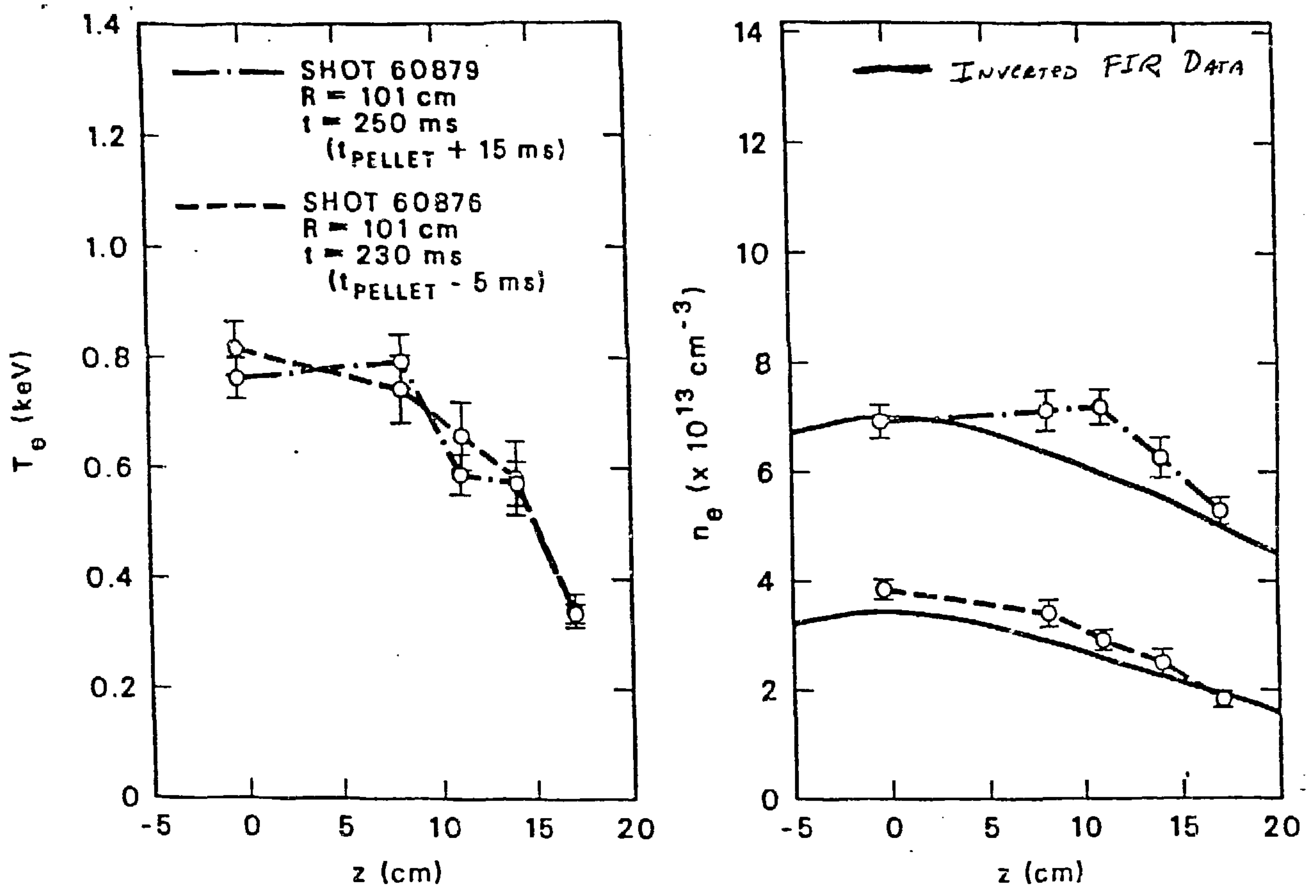
POOR GETTERING



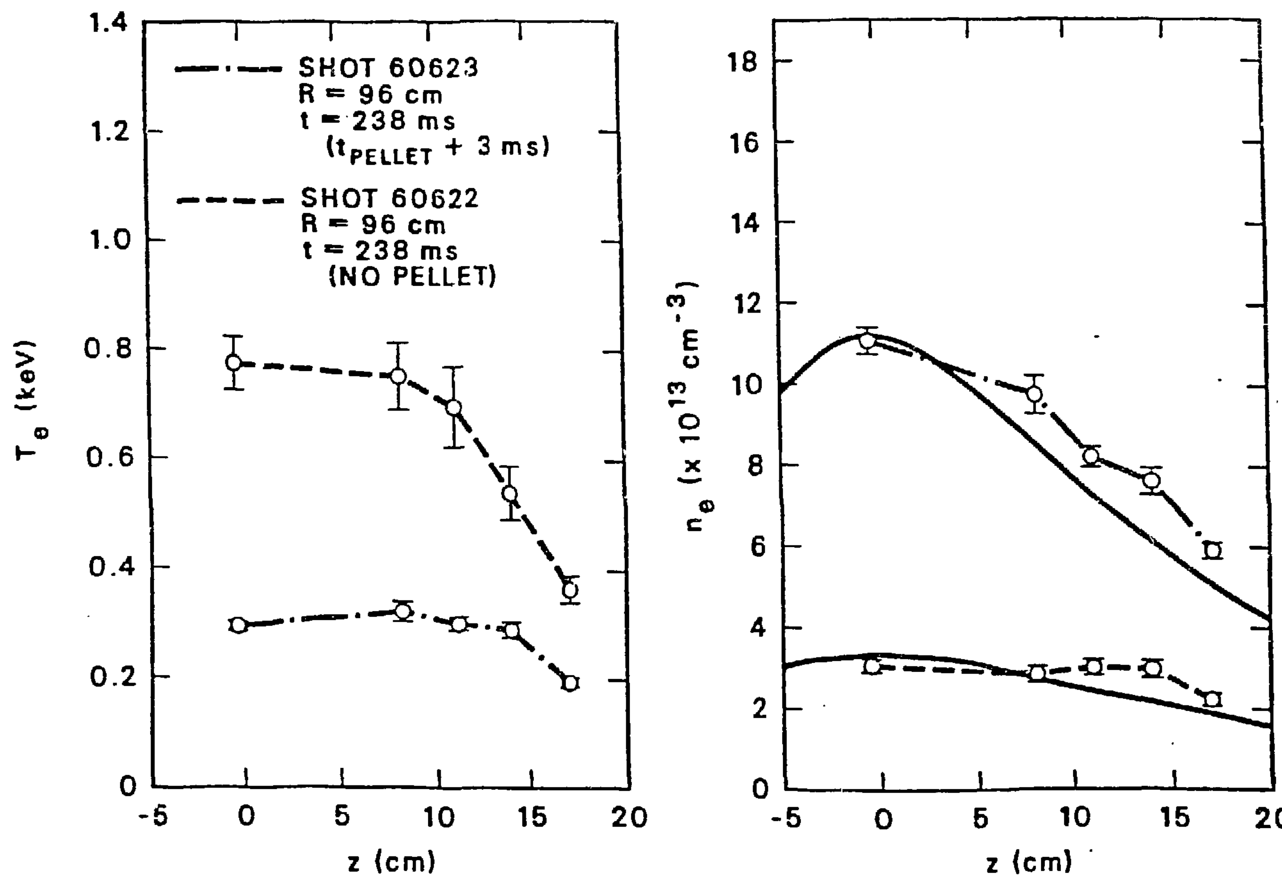
WELL-GETTERED



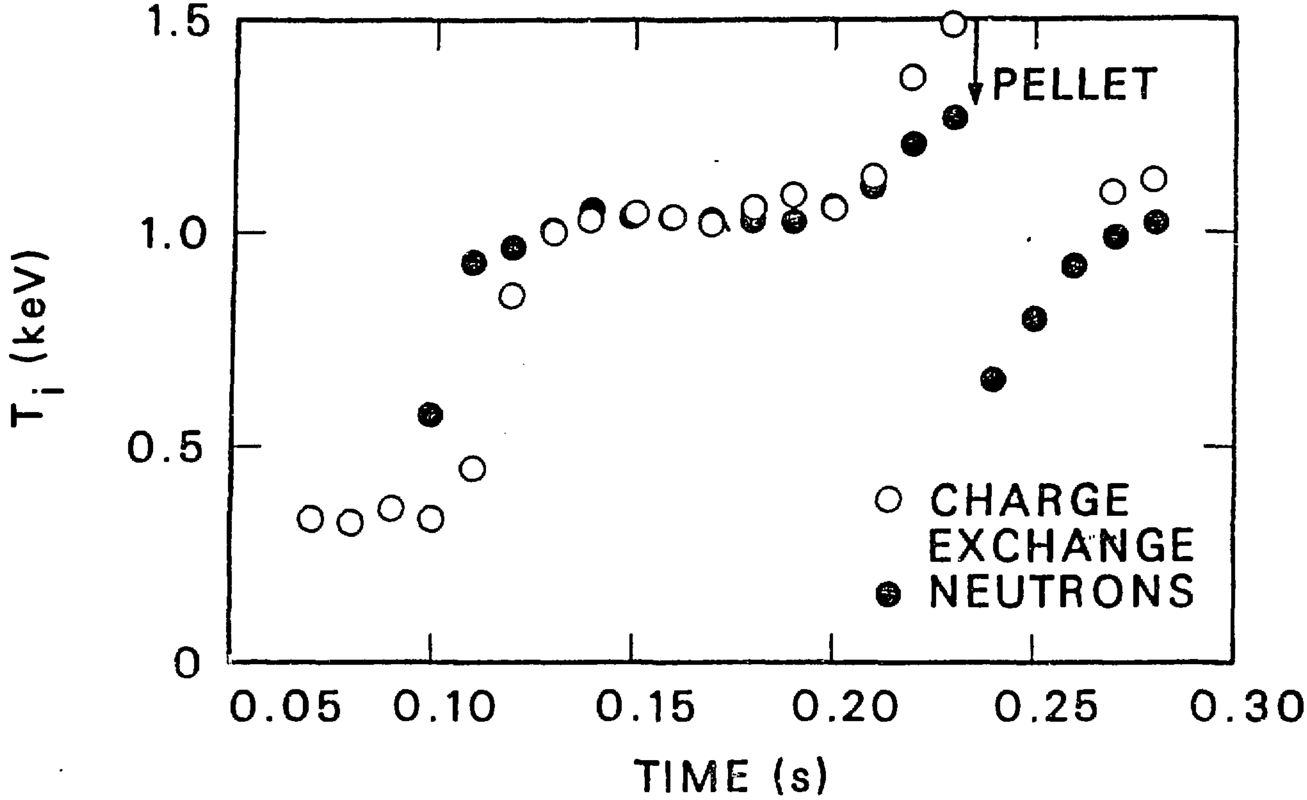
ORNL-DWG 85C-3508 FED



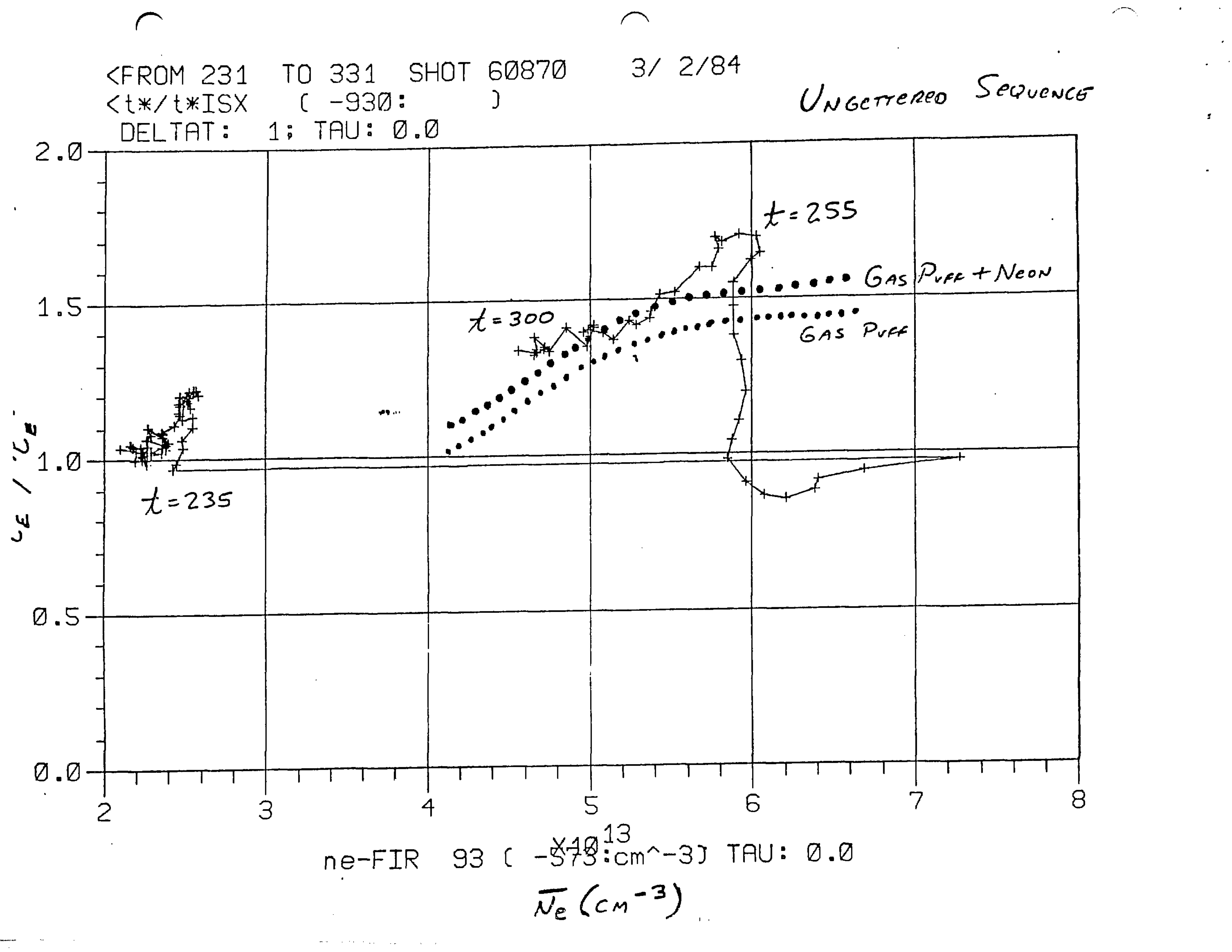
ORNL-DWG 85C-3509 FED

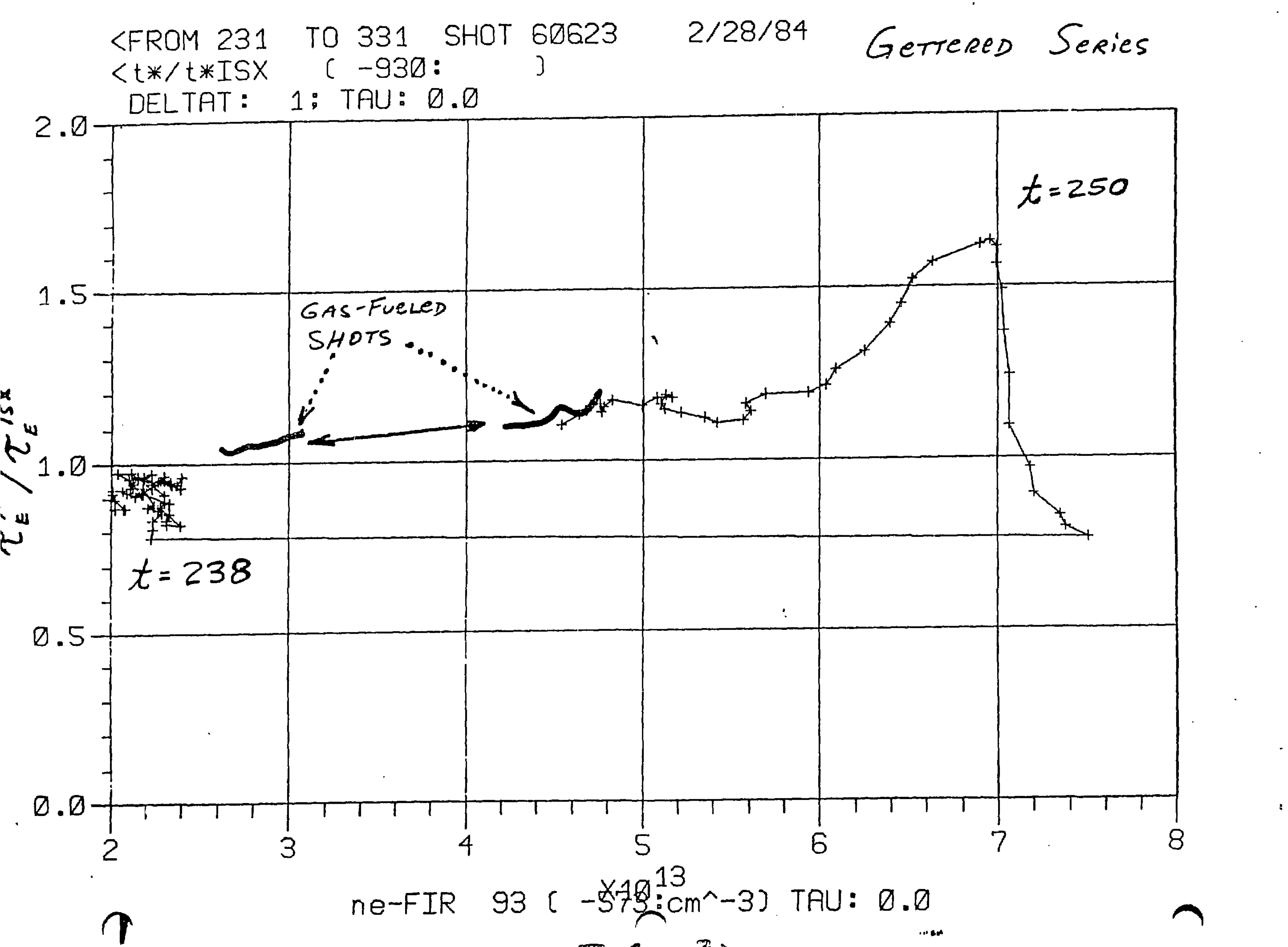


ORNL-DWG 85C-3504 FED



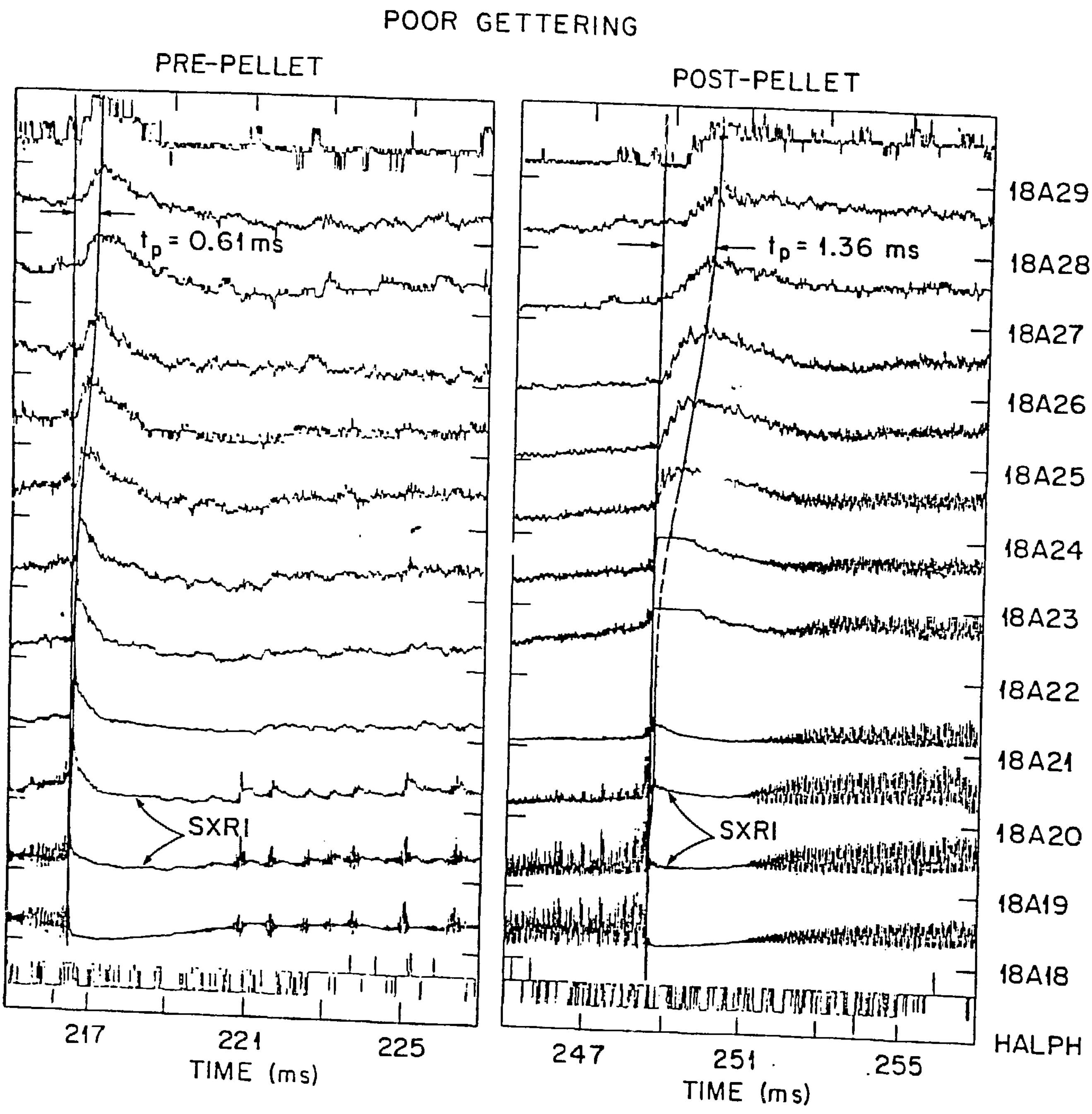
UNGETTERED SEQUENCE


<FROM 231 TO 331 SHOT 60870 3/ 2/84
<t*/t*ISX (-930:)
DELTAT: 1; TAU: 0.0
UNGETTERED SEQUENCE
t = 255
t = 300
t = 235
GAS PUFF + NEON
GAS PUFF
2.0
1.5
1.0
0.5
0.0
2
3
4
5
6
7
8
X10 13
ne-FIR 93 (-573:cm^-3) TAU: 0.0
Ne (cm^-3)



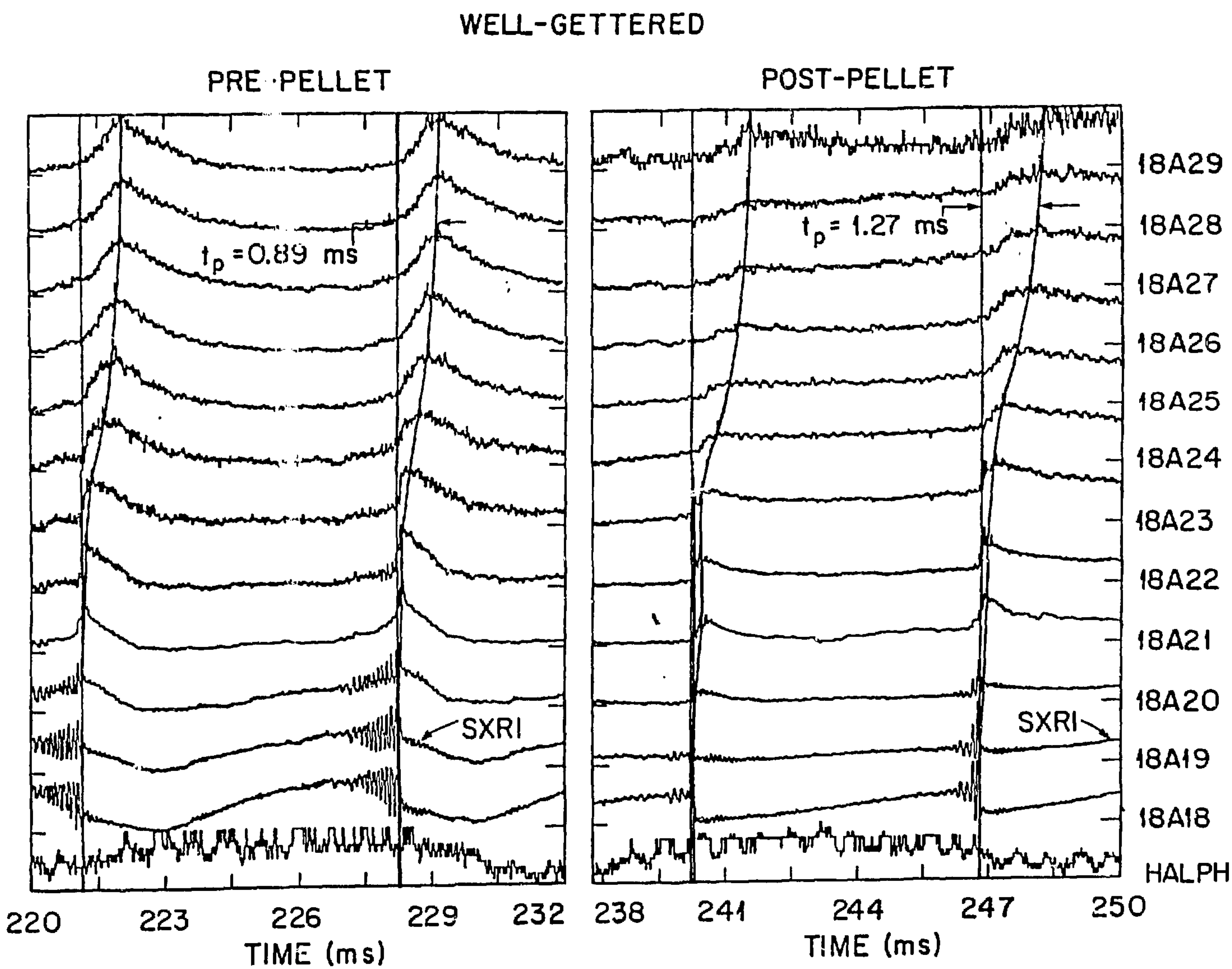
<FROM 231 TO 331 SHOT 60623 2/28/84
<t*/t*ISX (-930:)
DELTAT: 1; TAU: 0.0
GETTERED SERIES
t=250
t=238
GAS-FUELED
SHOTS
2.0
1.5
1.0
0.5
0.0
2
3
4
5
6
7
8
X10^13
ne-FIR 93 (-575:cm^-3) TAU: 0.0

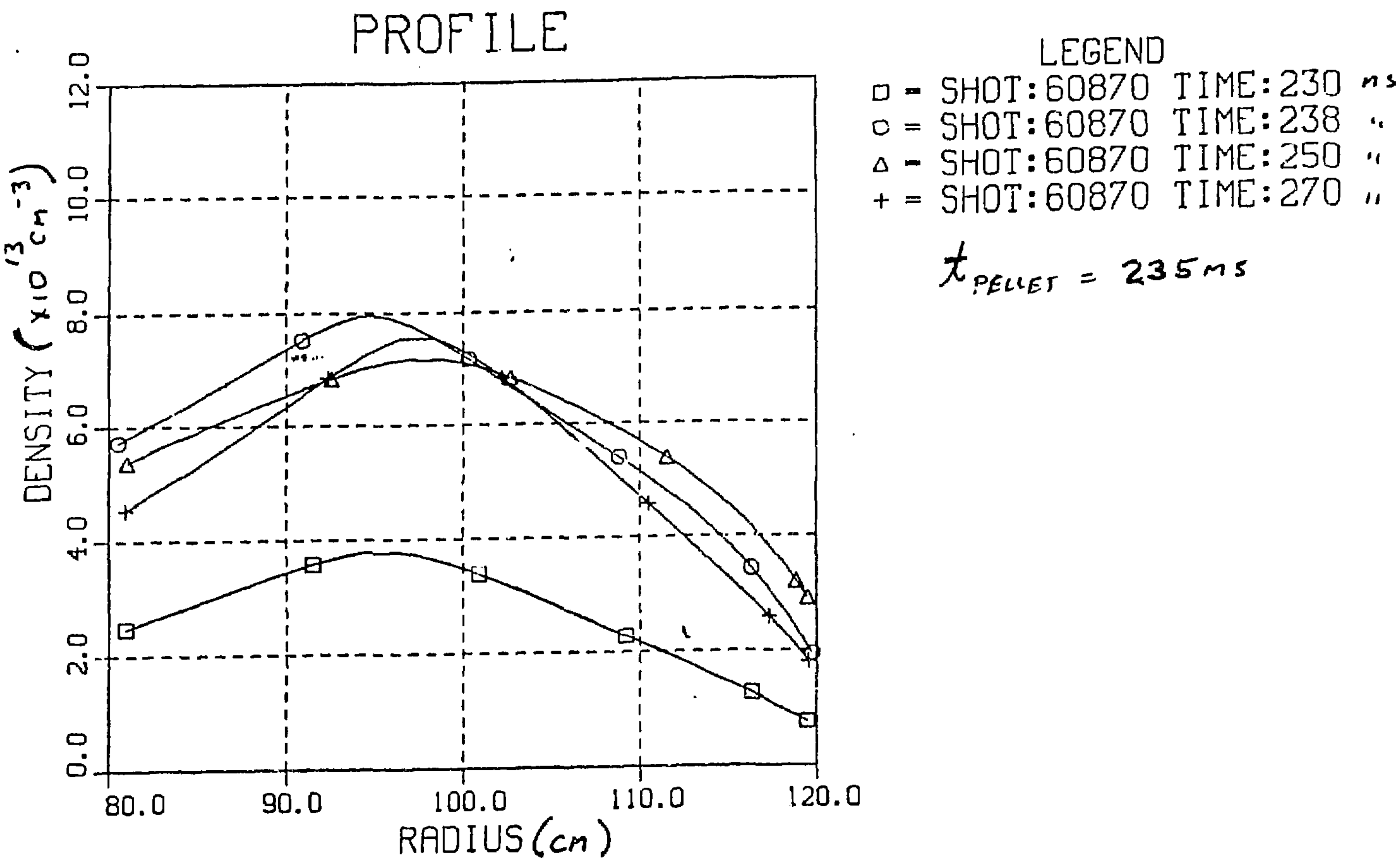
ORNL-DWG 85-3595 FED



Heat Pulse Propagation (SXR Array)

ORNL-DWG 85-3596 FED





UNGETTERED SEQUENCE

TRIGGERING P–MODE BEHAVIOR DEPENDS UPON:

- Pellet Penetration (Compare 2-Shots into Gettered Plasma at Different P_B)

- Pre–Pellet Plasma q–Profile (Sequence of One and Two Pellet Shots into Ungettered Small Plasma)

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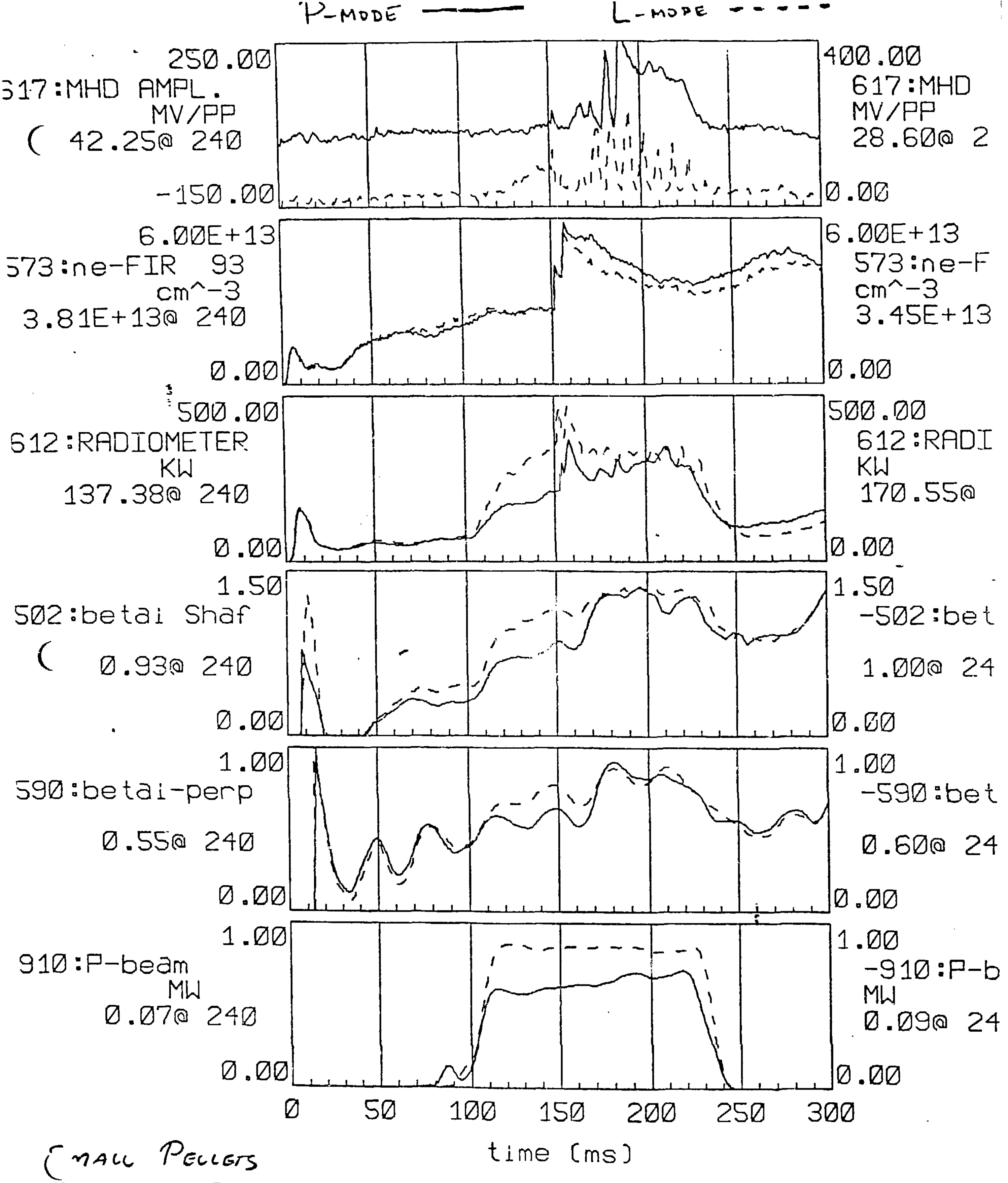
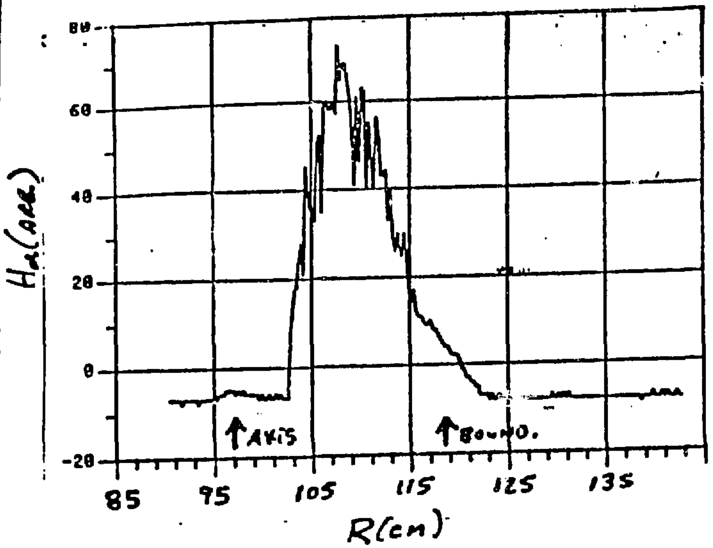


Small Pellets
Gettered Plasma

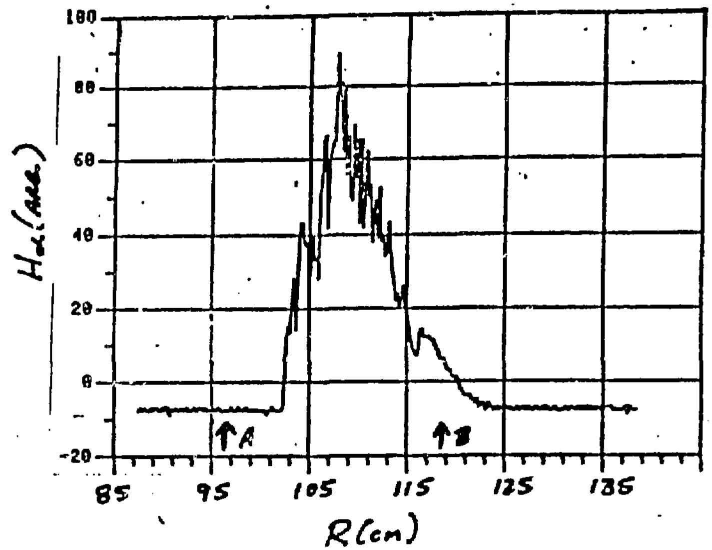
PLOTCH 28-OCT-85/ENE

"L-MODE" SHOT

1ST PELLET

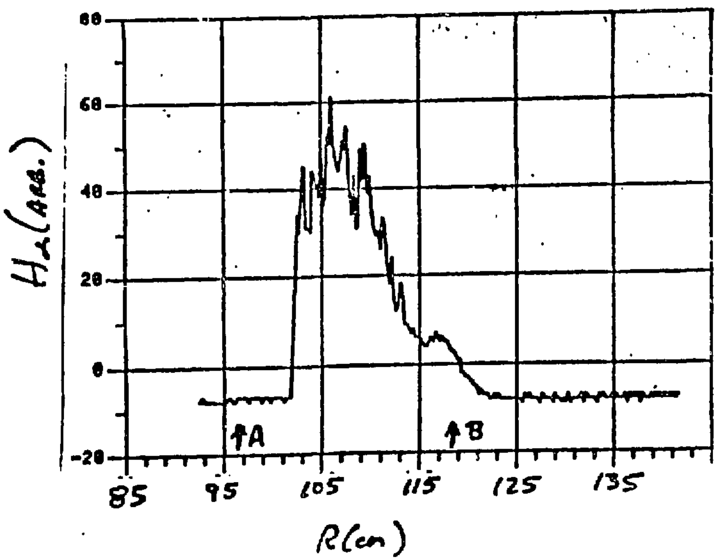


2ND PELLET

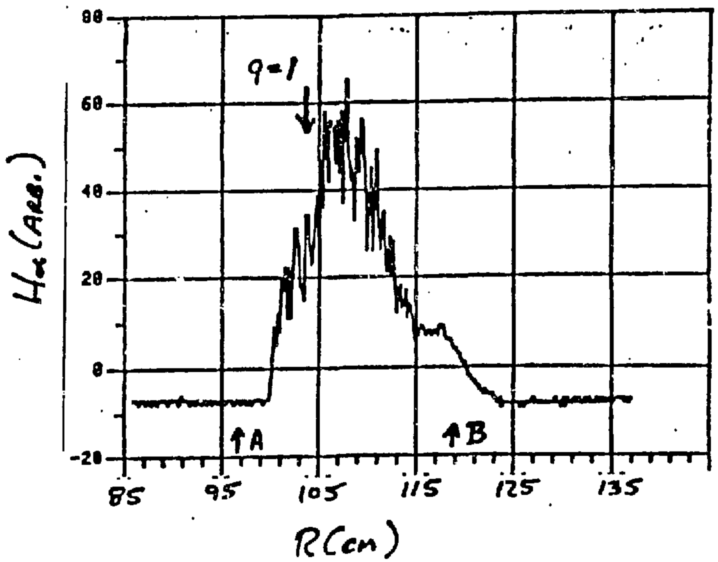


"P-MODE" SHOT

1ST PELLET

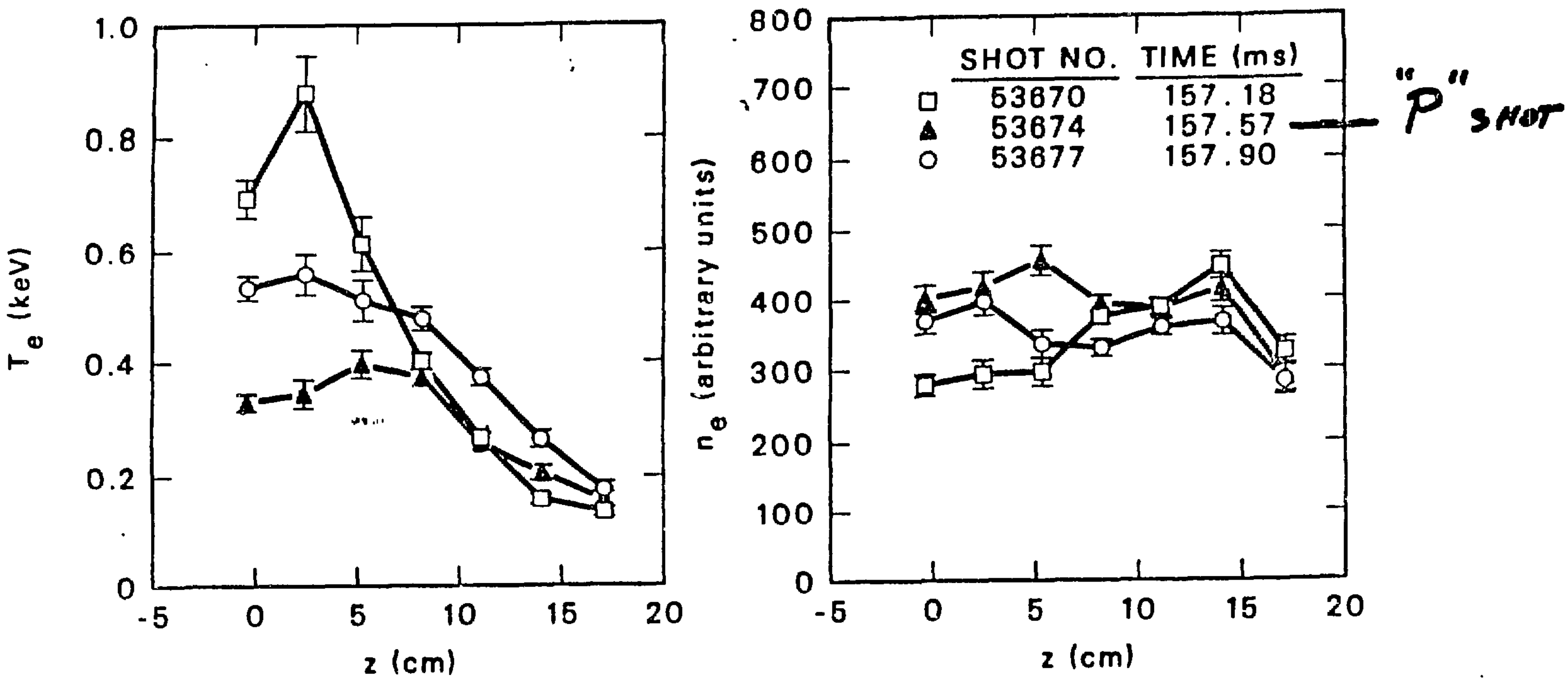


2ND PELLET



2ND PELLET CROSSES $q=1$ SURFACE

ORNL-DWG 85C-3507 FED



PROFILE SEQUENCE FOLLOWING PELLET INJ.

SERIES OF SHOTS WITH 1 OR 2 PELLETS; SMALL PLASMA; NO GETTERING

- **Single-Pellet Shots:**

  3 P-Mode

  5 "L" Mode
  (no change in τ_p^* , density scaling of τ_E^*)

  0 Prompt Disruptions

- **Two-Pellet Shots:**

  5 P-Mode

  0 "L" Mode

  2 Prompt Disruptions

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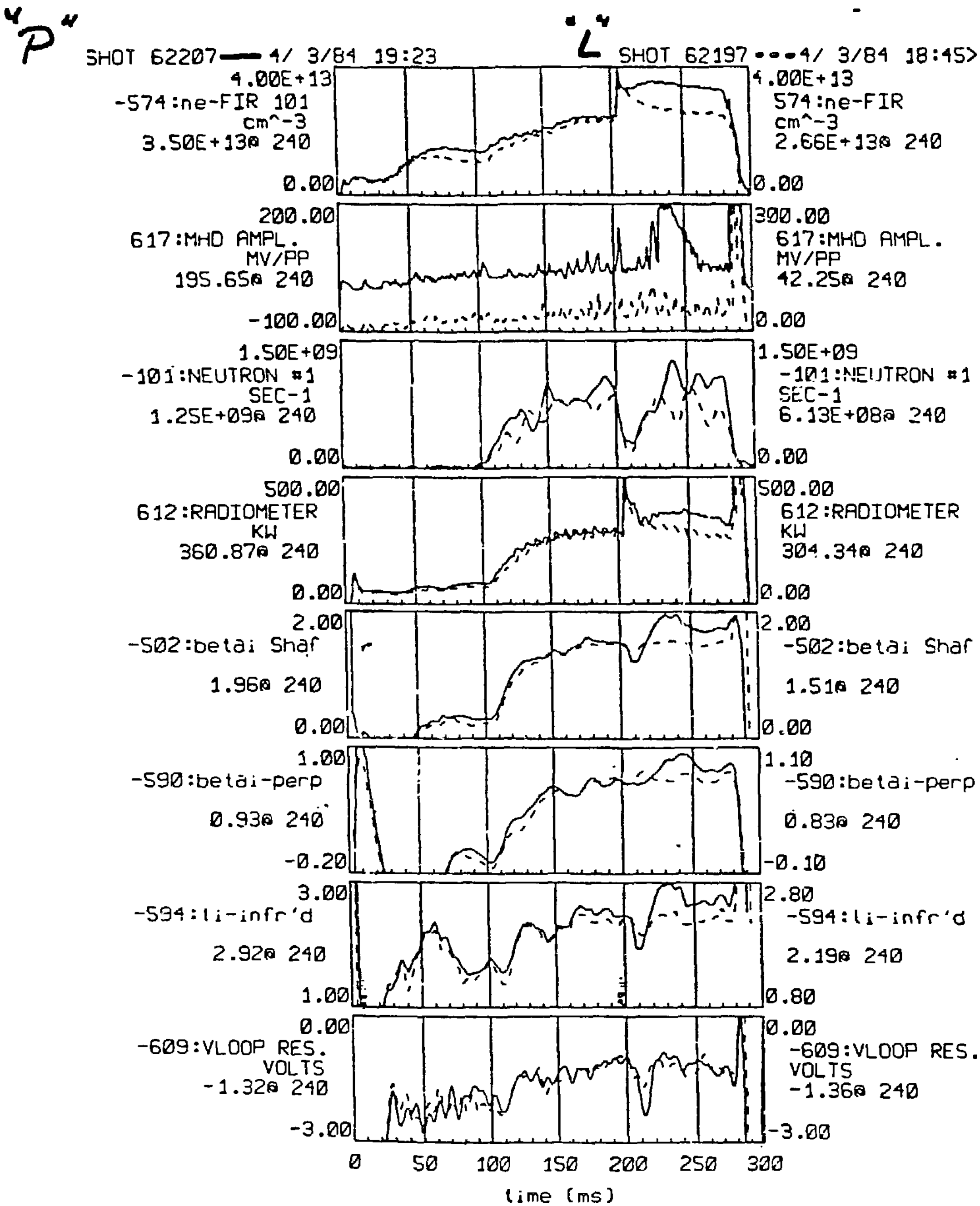
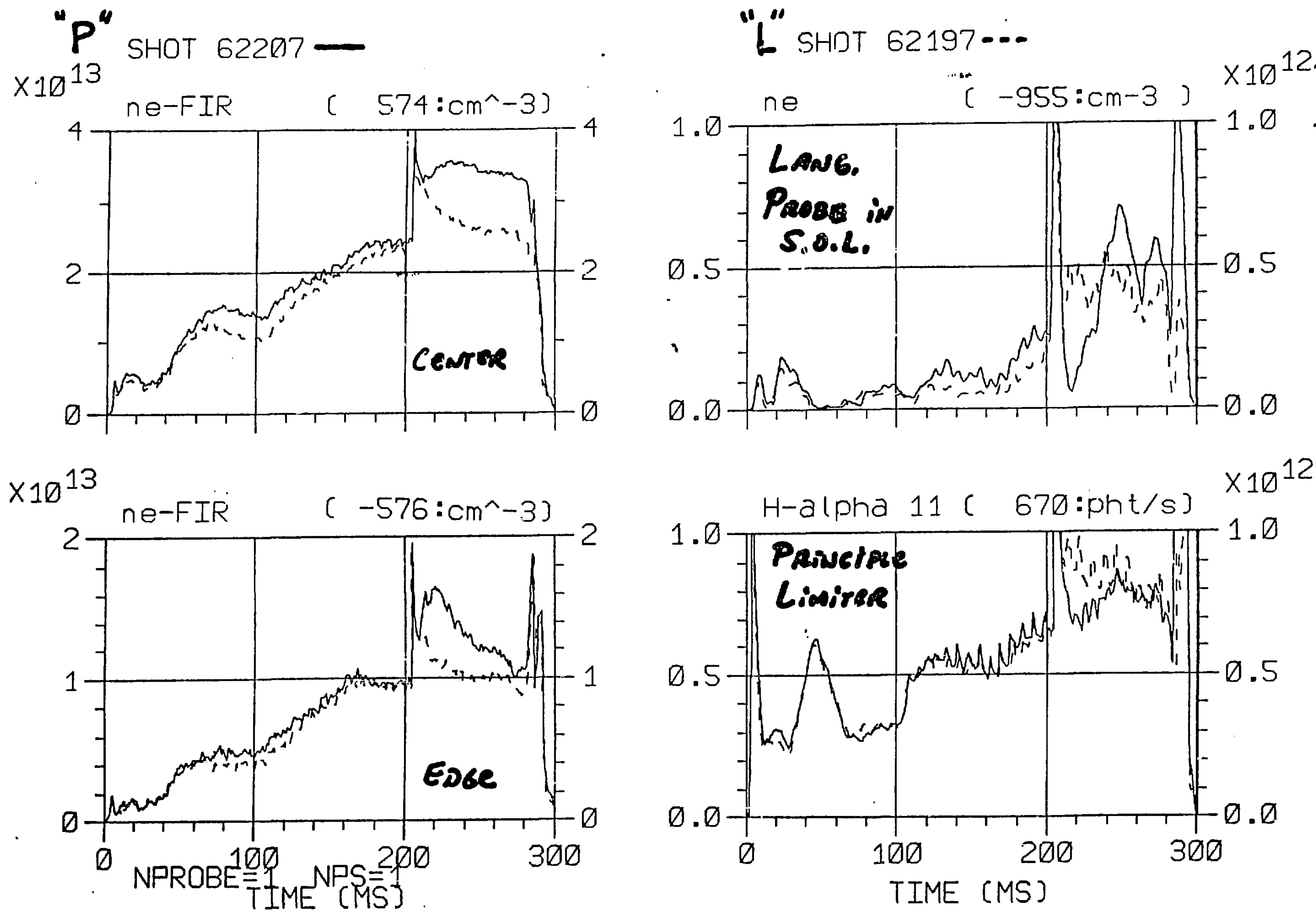
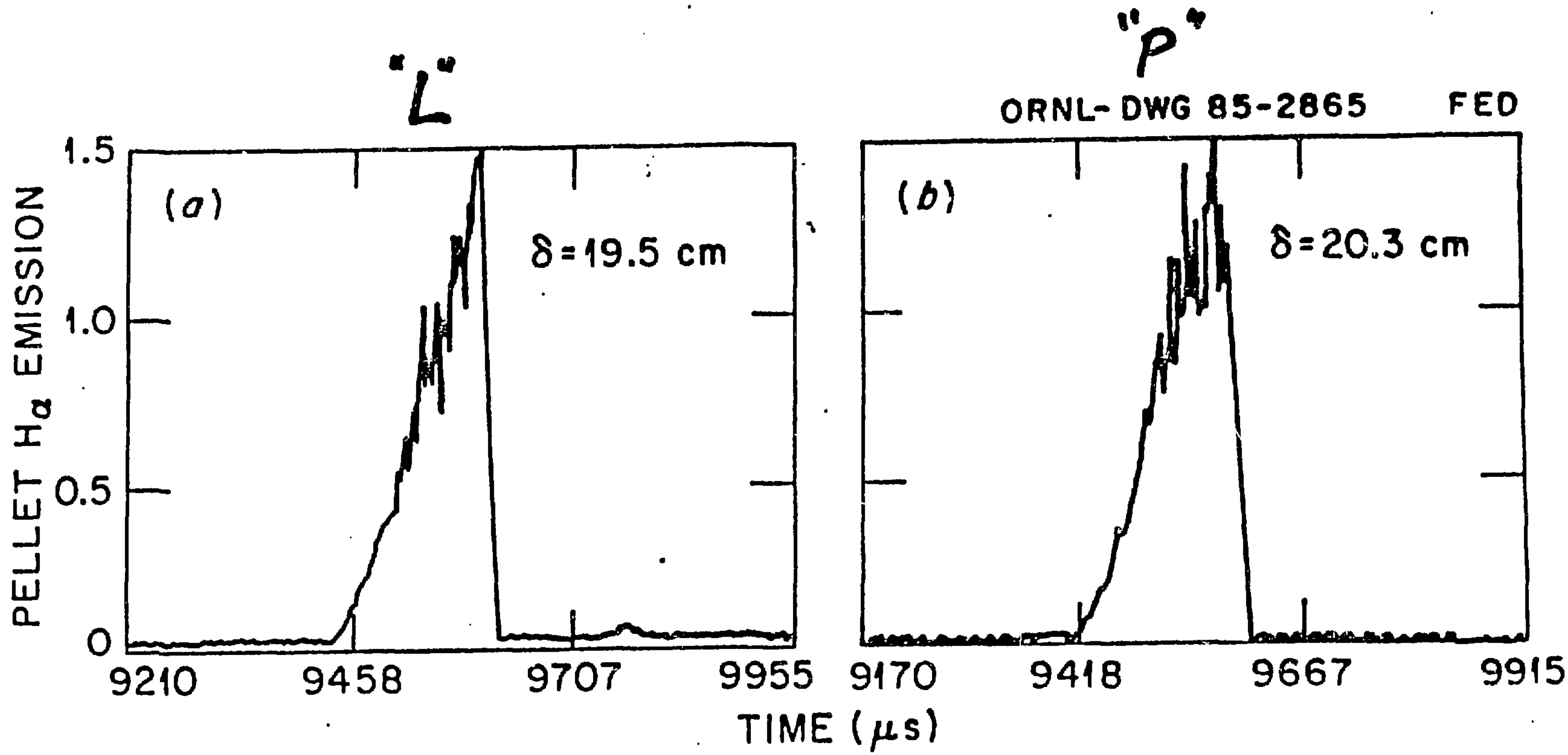
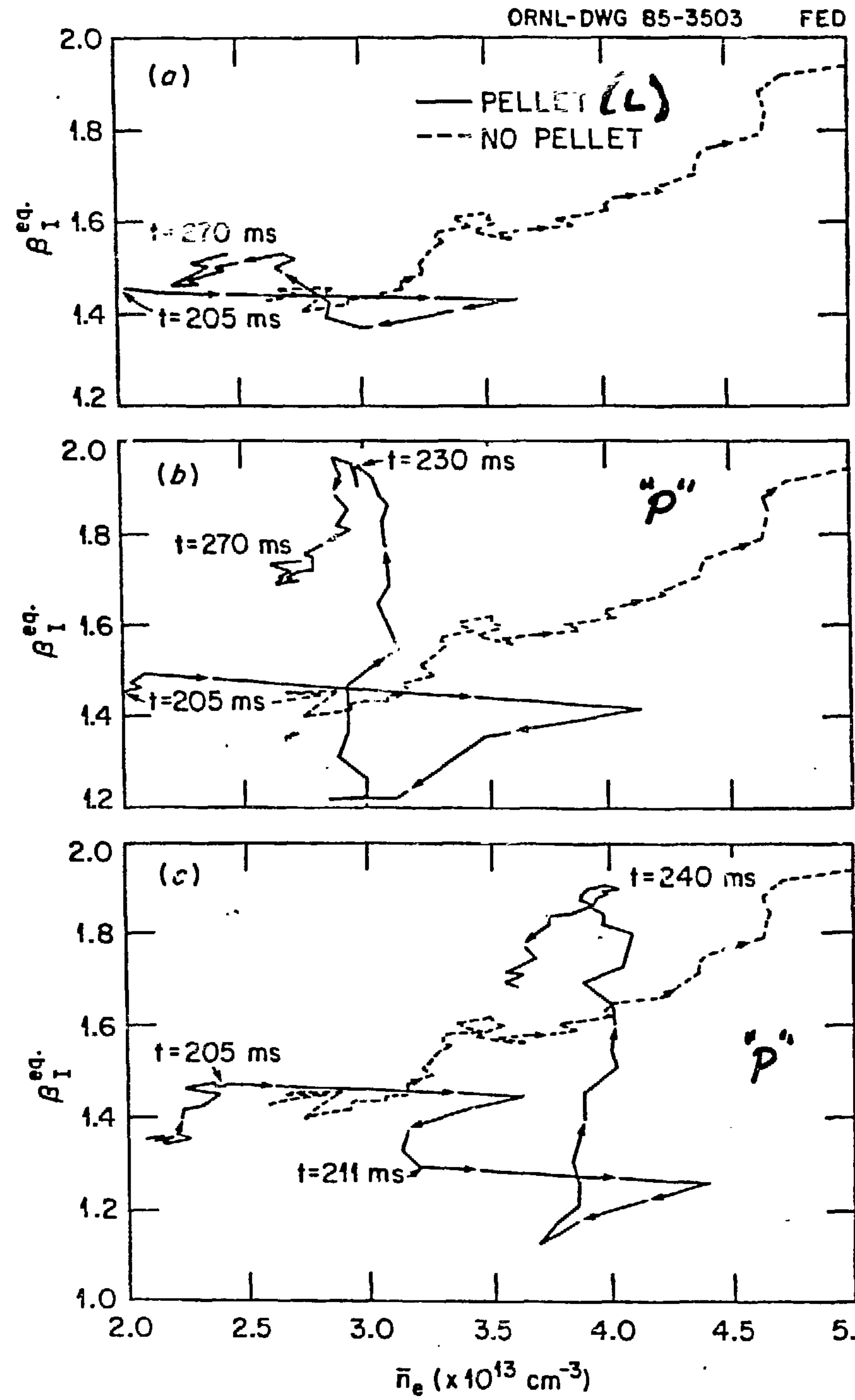

"P" SHOT 62207 —— 4/ 3/84 19:23
"L" SHOT 62197 ---- 4/ 3/84 18:45>
4.00E+13
-574:ne-FIR 101
cm^-3
3.50E+13@ 240
0.00
4.00E+13
574:ne-FIR
cm^-3
2.66E+13@ 240
0.00
200.00
617:MHD AMPL.
MV/PP
195.65@ 240
-100.00
300.00
617:MHD AMPL.
MV/PP
42.25@ 240
0.00
1.50E+09
-101:NEUTRON #1
SEC-1
1.25E+09@ 240
0.00
1.50E+09
-101:NEUTRON #1
SEC-1
6.13E+08@ 240
0.00
500.00
612:RADIOMETER
KW
360.87@ 240
0.00
500.00
612:RADIOMETER
KW
304.34@ 240
0.00
2.00
-502:betai Shaf
1.96@ 240
0.00
2.00
-502:betai Shaf
1.51@ 240
0.00
1.00
-590:betai-perp
0.93@ 240
-0.20
1.10
-590:betai-perp
0.83@ 240
-0.10
3.00
-594:li-infr'd
2.92@ 240
1.00
2.80
-594:li-infr'd
2.19@ 240
0.80
0.00
-609:VLOOP RES.
VOLTS
-1.32@ 240
-3.00
0.00
-609:VLOOP RES.
VOLTS
-1.36@ 240
-3.00
0 50 100 150 200 250 300
time (ms)



"P" SHOT 62207 ——
X10^13
ne-FIR (574:cm^-3)
4
2
0
CENTER
X10^13
ne-FIR (-576:cm^-3)
2
1
0
EDGE
0
100
200
300
NPROBE=1 NPS=1
TIME (MS)
"L" SHOT 62197 - - -
X10^12.
ne (-955:cm-3)
1.0
0.5
0.0
LANG. PROBE IN S.O.L.
X10^12
H-alpha 11 (670:pht/s)
1.0
0.5
0.0
PRINCIPLE LIMITER
0
100
200
300
TIME (MS)



"L"
"P"
ORNL-DWG 85-2865 FED
PELLET Hα EMISSION
1.5
1.0
0.5
0
(a)
δ=19.5 cm
9210
9458
9707
9955
(b)
δ=20.3 cm
9170
9418
9667
9915
TIME (μs)



ORNL-DWG 85-3503 FED
(a)
PELLET (L)
NO PELLET
t=270 ms
t=205 ms
(b)
"P"
t=230 ms
t=270 ms
t=205 ms
(c)
t=240 ms
"P"
t=205 ms
t=211 ms
$\beta_I^{eq.}$
2.0
1.8
1.6
1.4
1.2
1.0
2.0
2.5
3.0
3.5
4.0
4.5
5.0
$\bar{n}_e$ ($\times 10^{13}$ cm^{-3})

- P–Mode pushes confinement boundary to 1.7 – 2.0 times ISX-B scaling at densities ranging from 4×10^{13} cc^{-1} to 6×10^{13} cc^{-1}

- Some shots disrupt at this limit (t pellet + 15 ms) although density is well below disruption limit for gas-fueled discharges

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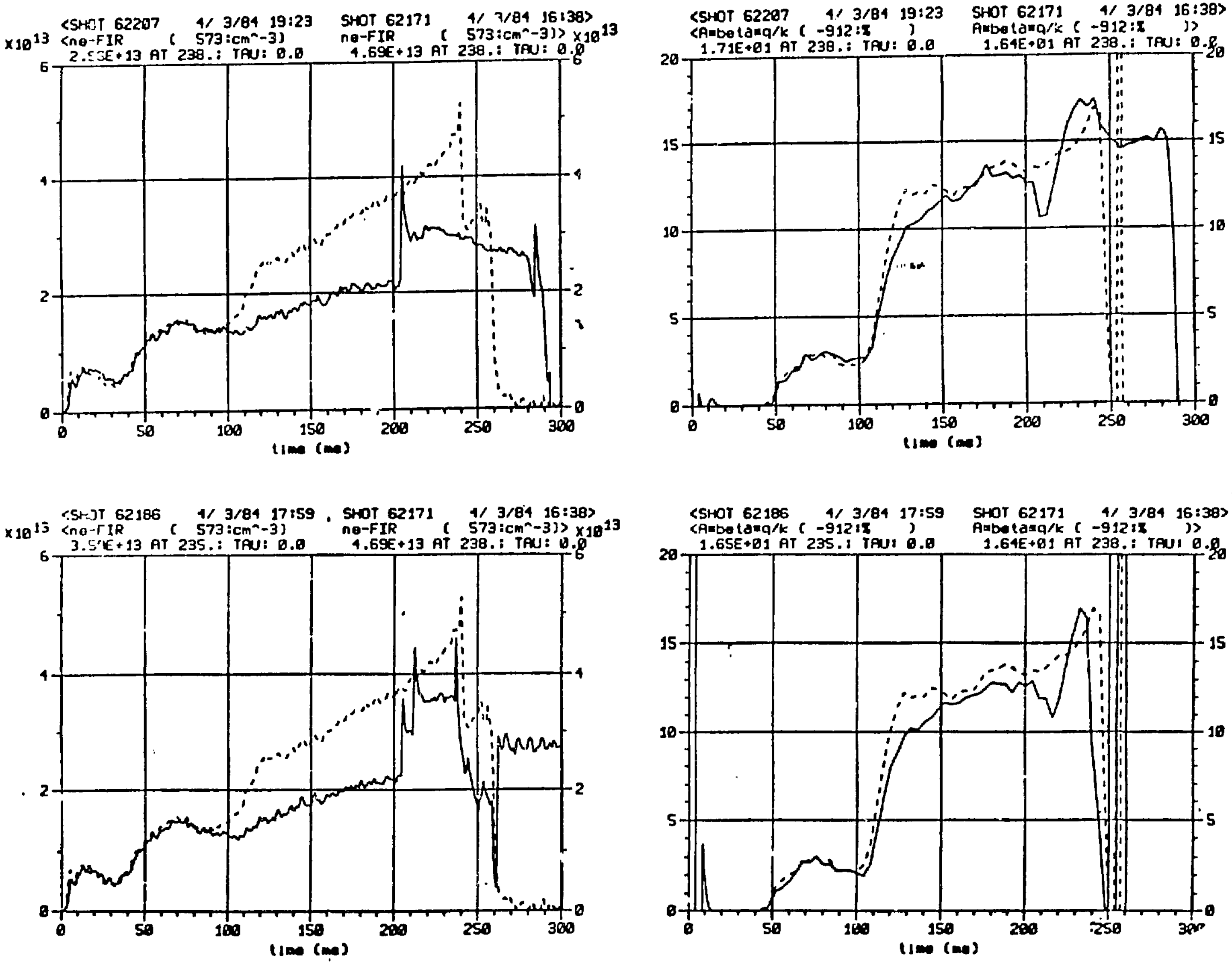


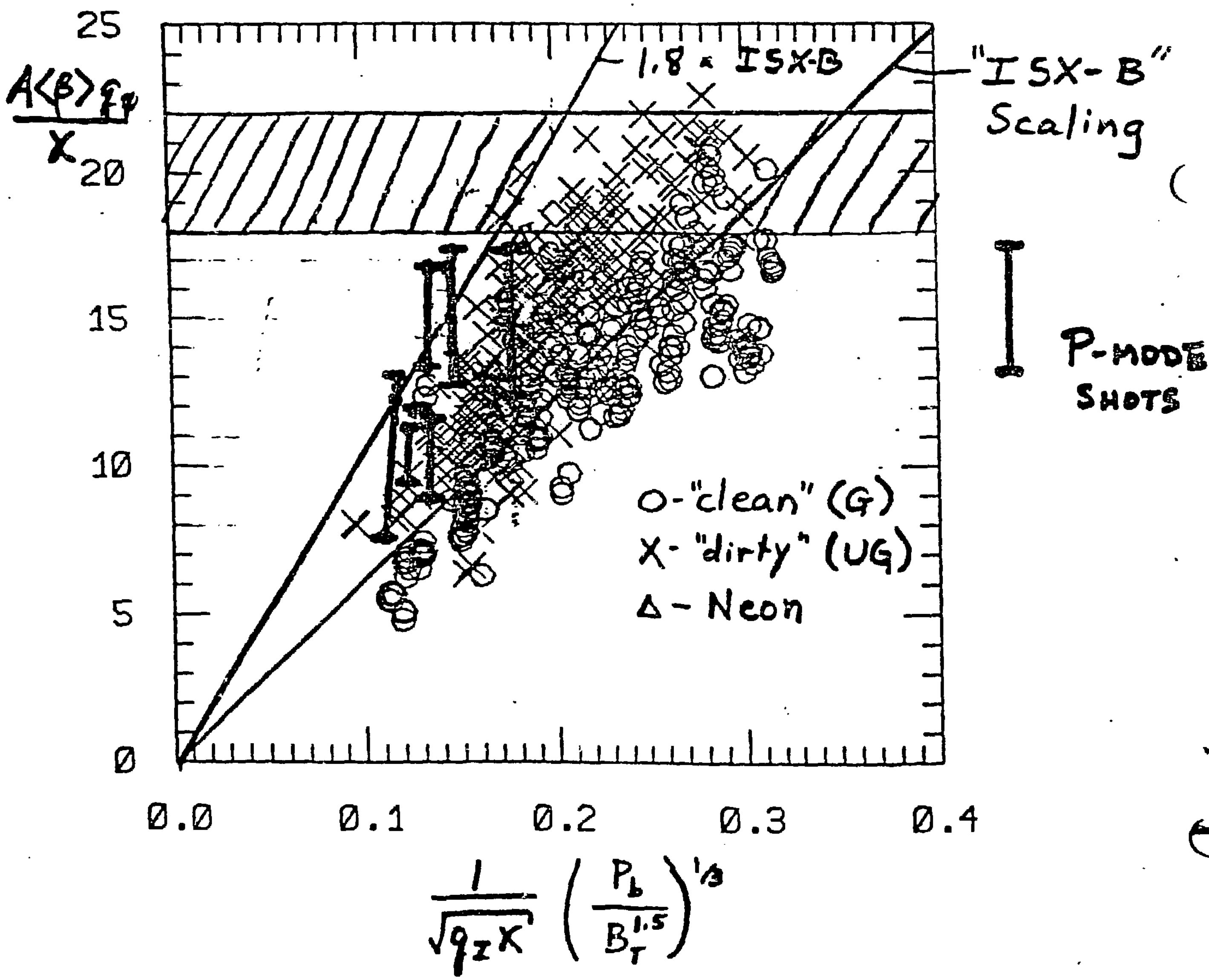
<SHOT 62207 4/ 3/84 19:23 SHOT 62171 4/ 3/84 16:38>
<ne-FIR (573:cm^-3) ne-FIR (573:cm^-3)>
2.55E+13 AT 238.: TAU: 0.0 4.69E+13 AT 238.: TAU: 0.0
x10^13
time (ms)
<SHOT 62207 4/ 3/84 19:23 SHOT 62171 4/ 3/84 16:38>
<A=beta*q/k (-912:%) A=beta*q/k (-912:%)>
1.71E+01 AT 238.: TAU: 0.0 1.64E+01 AT 238.: TAU: 0.0
time (ms)
<SHOT 62186 4/ 3/84 17:59 , SHOT 62171 4/ 3/84 16:38>
<ne-FIR (573:cm^-3) ne-FIR (573:cm^-3)>
3.5?E+13 AT 235.: TAU: 0.0 4.69E+13 AT 238.: TAU: 0.0
x10^13
time (ms)
<SHOT 62186 4/ 3/84 17:59 SHOT 62171 4/ 3/84 16:38>
<A=beta*q/k (-912:%) A=beta*q/k (-912:%)>
1.65E+01 AT 235.: TAU: 0.0 1.64E+01 AT 238.: TAU: 0.0
time (ms)

PELLET ——— GAS - - - - -

• The empirical confinement scaling implies:

$$\frac{A\langle\beta\rangle q_\psi}{\kappa} \propto \frac{1}{(q_I\kappa)^{1/2}}\left(\frac{P_b}{B_T{}^{1.5}}\right)^{1/3}$$

• In the Z-mode, confinement time is increased by up to ×1.8, but $A\langle\beta\rangle q_\psi/\kappa$-values are no higher.



CONCLUSIONS

- P-mode observed
  - Increased τ_p^*, τ_E^*
  - Distinct from Z-mode (not density scaling; seen in gettered discharges)
  - Distinct from R-mode (occurs for shots run at R = 94 and R = 98; τ_p^* increase exceeds R-mode values)

- Onset depends upon interaction of pellet with plasma q-profile

- Longer t_{peak} for heat pulse propagation suggests reduced χ_E

- Termination is abrupt at 1.7 - 2.0 X ISX-B scaling; observe onset of m = 1 driven MHD activity and increase in high frequency MHD (f > 150 kHz)

- P-mode, Z-mode, and R-mode have much in common
  - Same energy confinement boundary
  - All show large changes in plasma particle balance ($\bar{n}_e$ increases with added neon, required gas puff rate lower by 5x at large R, improved τ_p^* following pellet injection)

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