Deuterium Pellet Mass Redistribution in TFTR NBI Heated Discharges

P2.10

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Introduction

•Pellets of solid hydrogen are used routinely for plasma fuelling and perturbation studies in tokamak discharges.[1].
•The pellet source function determines to a large extent the pellet's effectiveness either as a fuelling mechanism or as a perturbation.
•Understanding the pellet source function is therefore important in predicting results of pellet fuelling sequences or perturbations.

_ Pellet Source Function _
•Pellet Ablation Rate establishes a Local Pellet Source
-Ablation rate is determined by target plasma temperature, density and fast particle content as well as pellet speed and mass
-Ablation rate is modeled by neutral gas shielding model which determines the penetration depth [2]

•Effective Pellet Source however, does not correspond to local pellet source [3.4]. The effective pellet source is that source which is inferred from the density profile present following completion of both the ablation process and the symmetrization of the pellet perturbation in poloidal and toroidal directions.

•These two source functions differed due to a radial redistribution of the local source during the pellet entry and symmetrization process. In addition, pellet mass is lost from the confined plasma during the pellet entry and symmetrization process. Both radial redistribution and mass loss must be included to predict the effective pellet source.

_ Radial Redistribution Process _
•Since the pellet perturbation as determined by the effective pellet source is generally adiabatic locally [3], the radial redistribution of the pellet mass must occur on the time scale of the local ablation before the redistributed mass is heated.

•Study of the redistribution process will require measurements on the time scale of the pellet ablation process.

•In this paper :

-Demonstrate that the rapid pellet mass redistribution can be studied using high time resolution measurements of electron temperature

- Identify features of the redistribution process measured by the electron temperature response

-We introduce an empirical model of rapid, radial mass redistribution. We compare electron temperatures predicted by that model with measurements of electron temperature made with high time resolution during the pellet ablation process in TFTR discharge heated by NBI.

- TFTR discharges heated by NBI are chosen because they produce high ablation rates with pellets fully evaporated outside the plasma core.

[1] Milora, Nuc Fusion Review Paper, Nucl Fusion
[2] Kuteev, Nucl Fusion 1167 (1995)
[3] Baylor, Schmidt et al, Nucl Fusion, 32, Vol 12 p 2177.
[4] Asdex High Field Launch, IPP 1/304.

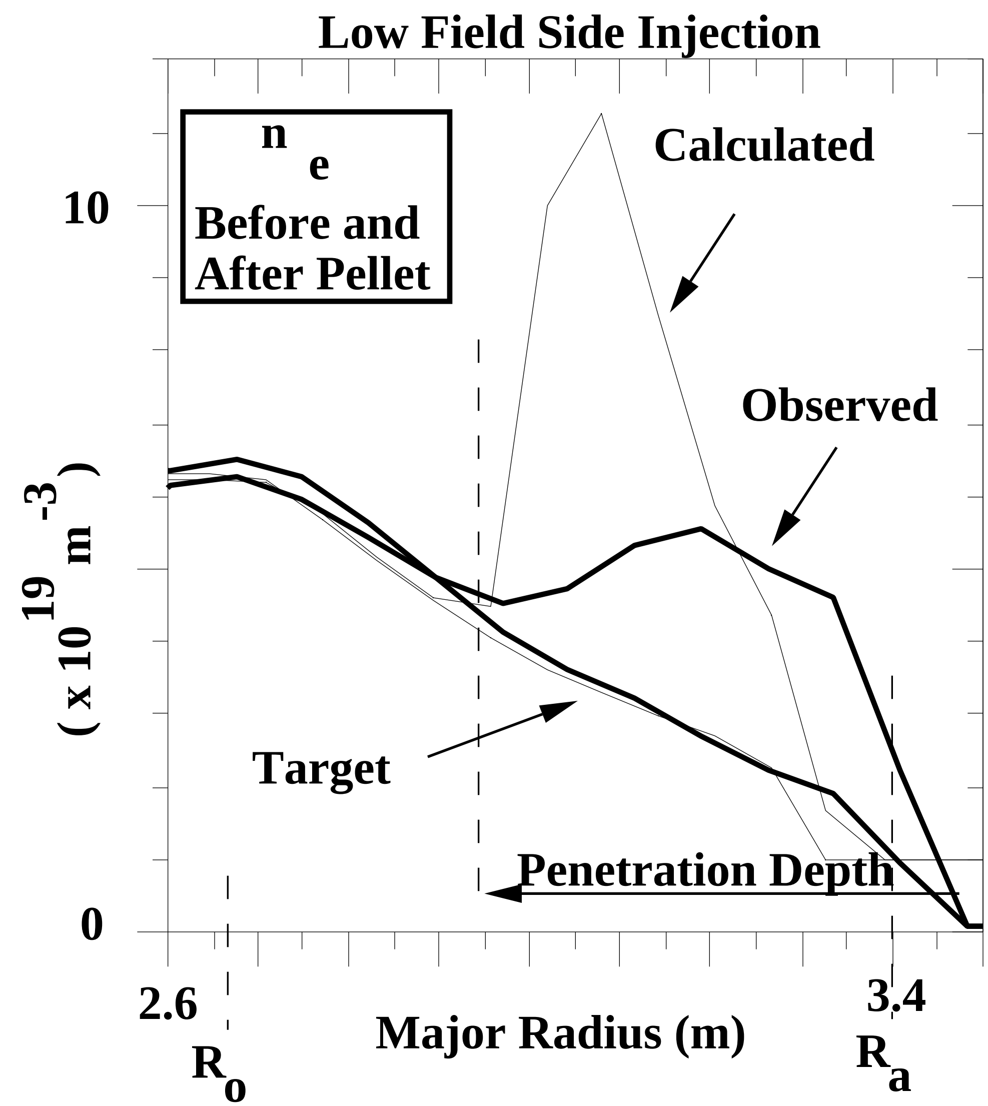
Pellet Fuelling Efficiency Affected by Pellet Penetration

- **Fuelling Efficiency Can Be Below 100%**
- **Fuelling Efficiency Decreases as Depth of Penetration Decreases**

Measured Radial Distribution of Pellet Source Not Consistent with Local Deposition Model for TFTR

- Penetration Depth Predicted
But Total Mass and Radial Profile Not Consistent with Measurement

- Deposited Mass Shifted Outward During Ablation and Symmetrization Process



Redistribution of Pellet Mass Takes Place on Time Scale of Ablation and Toroidal Symmetrization Process

• **Adiabatic character of perturbation and redistribution process [3] suggests high time resolution measurements of electron temperature might provide a mechanism to observe redistribution of pellet mass**

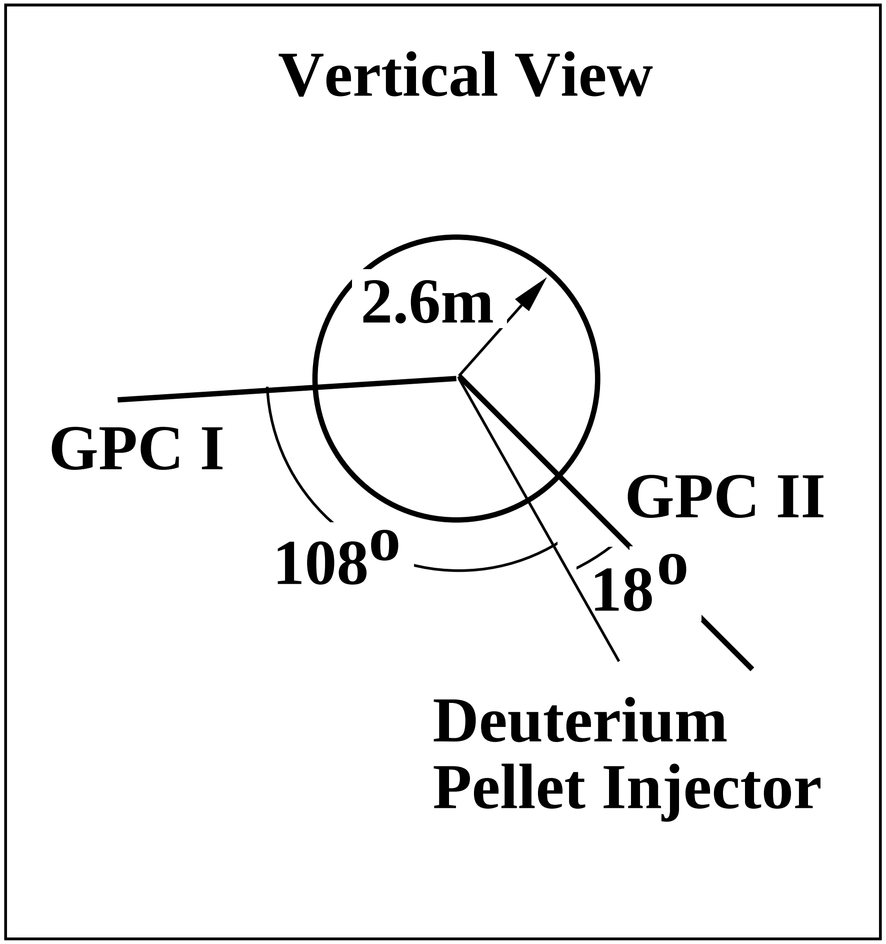
• **Time resolution required ~10 μs**
Density Symmetrization Process - 1 - 2 ms
Ablation Process - 300 - 500 μs

TFTR Fast Te Diagnostics Uniquely Well Suited to Study of Pellet Mass Redistribution

• Two ECE Grating PolyChrometers with high time resolution (>10ms).

• One instrument remote from injector.
 - GPC I located 108 Degrees toroidally from injector.

• One instrument near injector.
- GPC II located 18 Degrees from injector.



R(m)

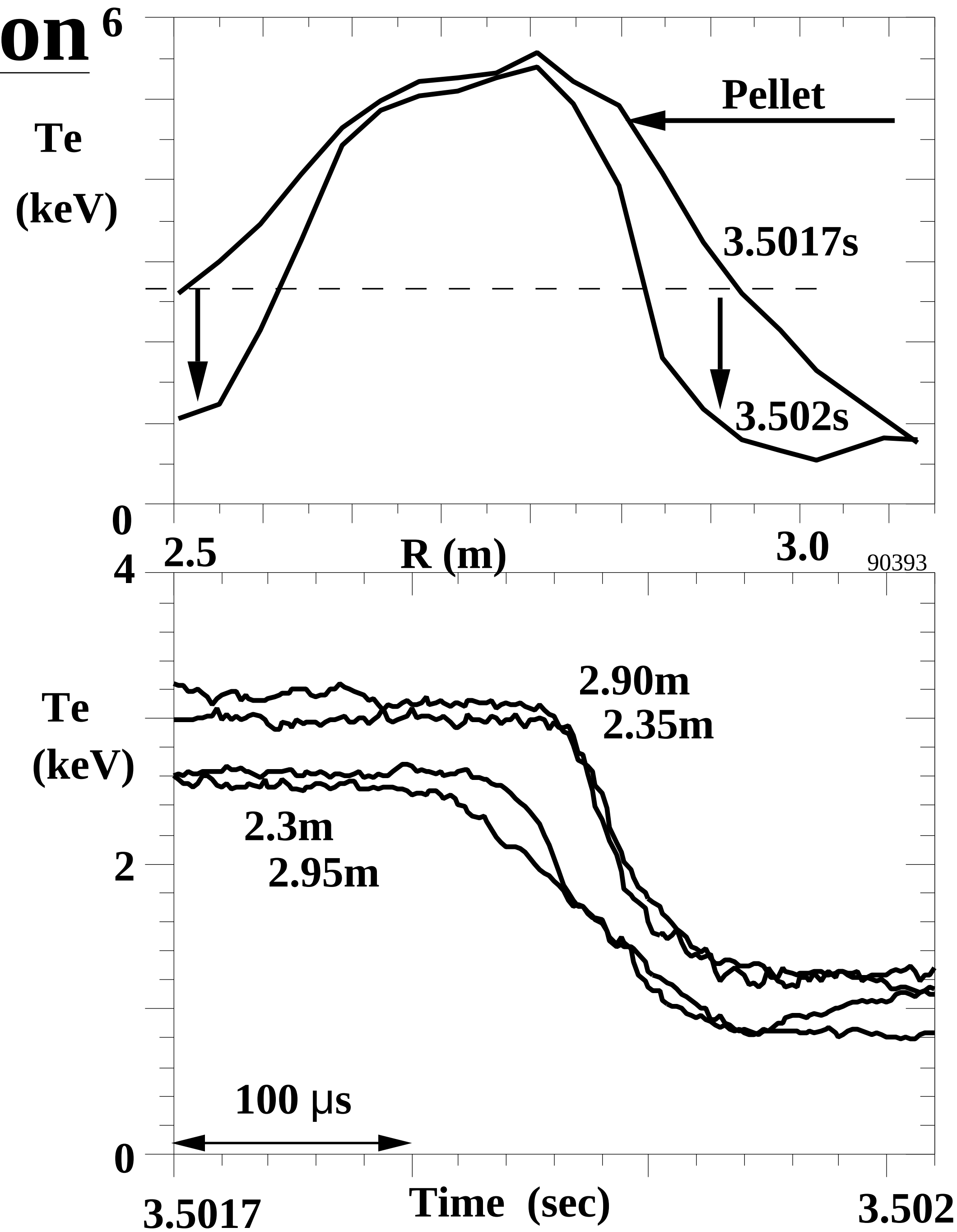
Te Response far from Injection Can Serve as Probe of Local Ablation Process

Pellet deposition at large major radius

Far from injection location ECE measurements on both sides of axis at similar initial temperature (same flux surface) show <20ms phase shift

Remote ECE measurements effectively reflect instantaneous deposition on flux surface

Measurements indicate mass redistribution takes place continuously throughout the ablation process

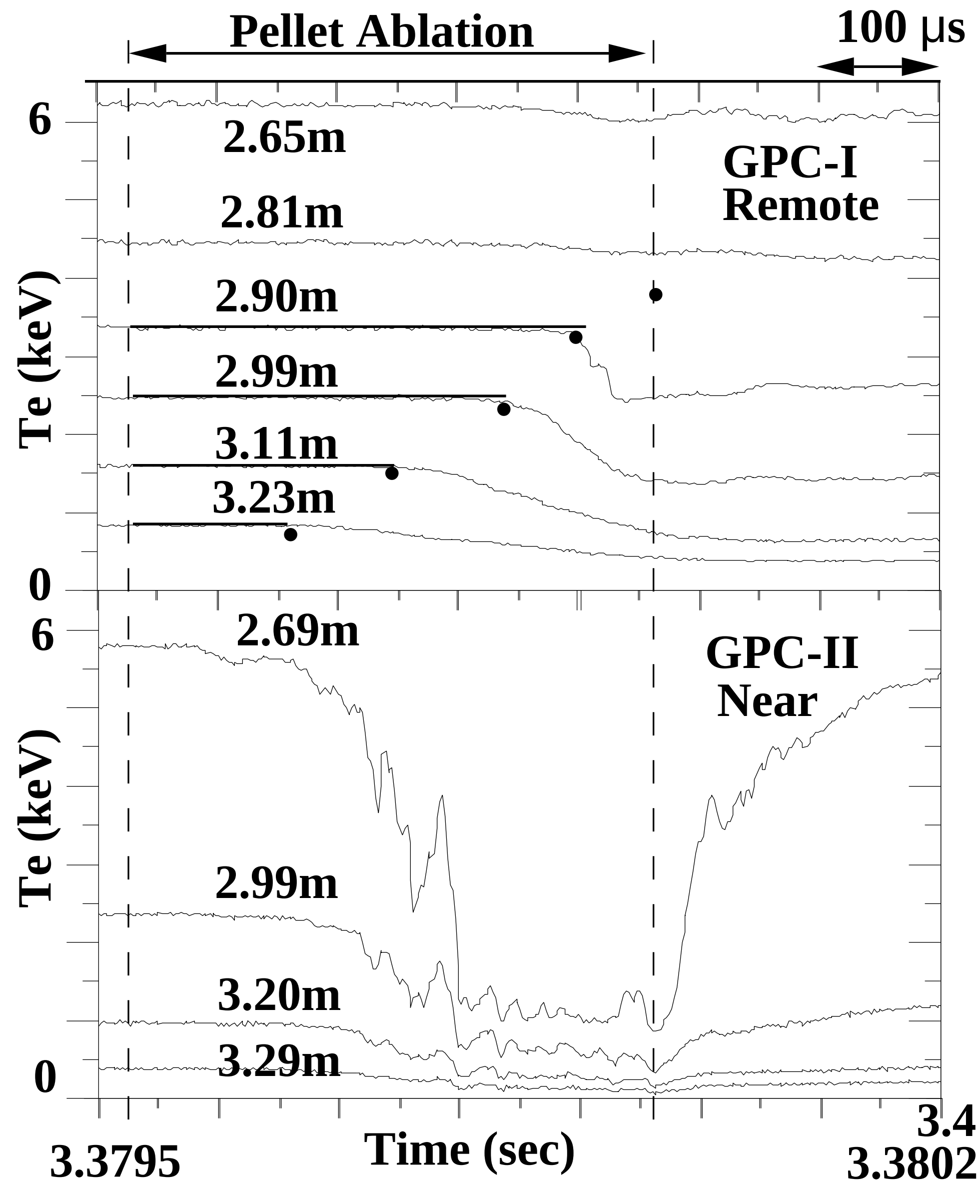


High time resolution Te measurements Reflect the Duration and Radial Extent of the Pellet Mass Redistribution

- Time scale of ECE response shows rapid Te symmetrization and slow ne symmetrization

- Measurements remote from injection location reflect instantaneous source and show apparent continuous redistribution throughout ablation process

- Radial extent and duration of measurement cutoff region for measurements near injection location shows spatial extent of pellet mass redistribution mechanism



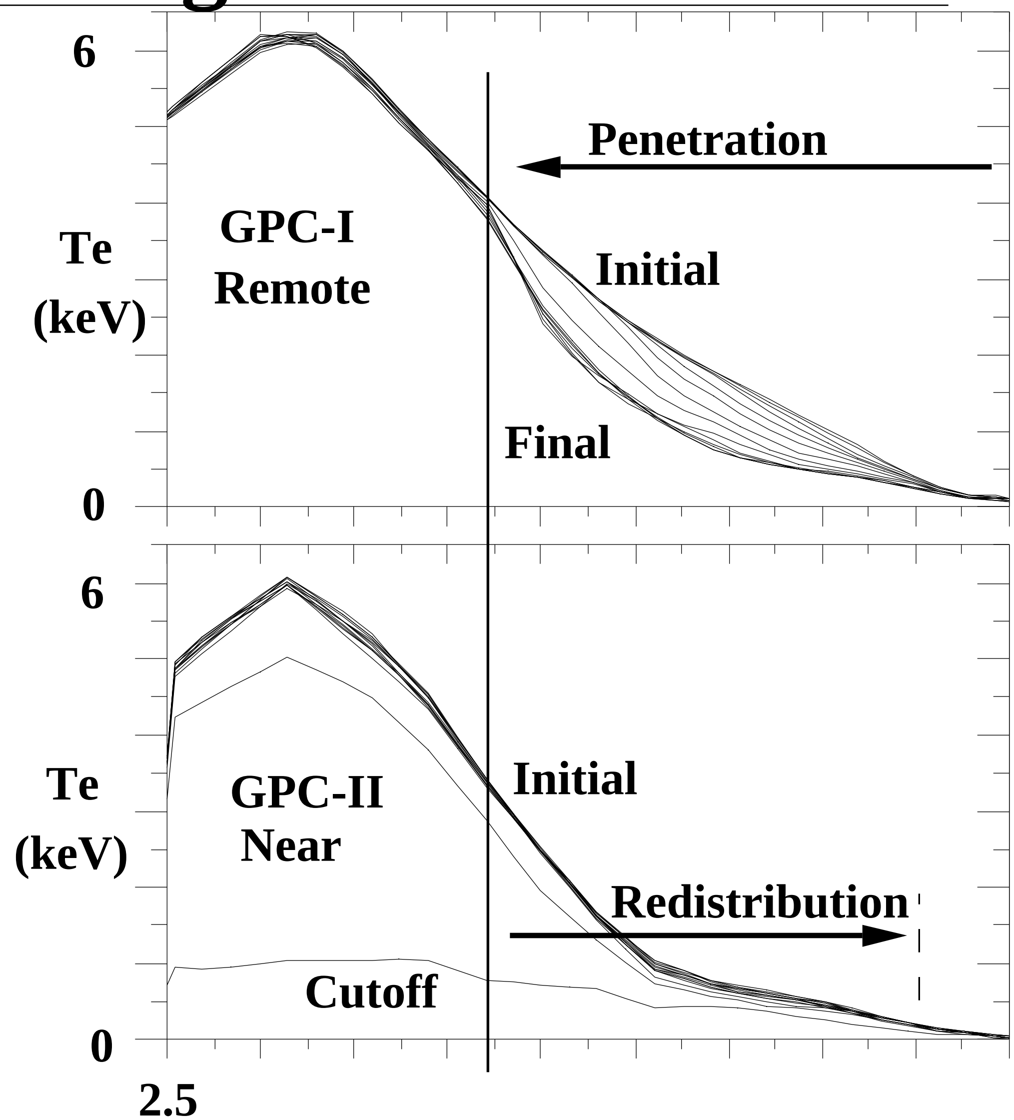
ECE Measurements Suggest Radial Extent of Redistribution Mechanism Extends to Near the Plasma Boundary Throughout the Ablation Process

•ECE Response remote from injection location reflects penetration depth

•Radial extent of cutoff region near injection location reflects radial extent of redistribution

•Cutoff extends to all radii throughout ablation process

•Since local pellet source moves radially inward during ablation process, continued cutoff of outer region throughout ablation period suggests redistribution extends to near plasma boundary



Simulate Te behavior with simple mass redistribution Model

Model: Components:

Local ablation rate given by local plasma parameters [2]

Redistribute ablated pellet mass uniformly across minor radius outside point of instantaneous pellet source

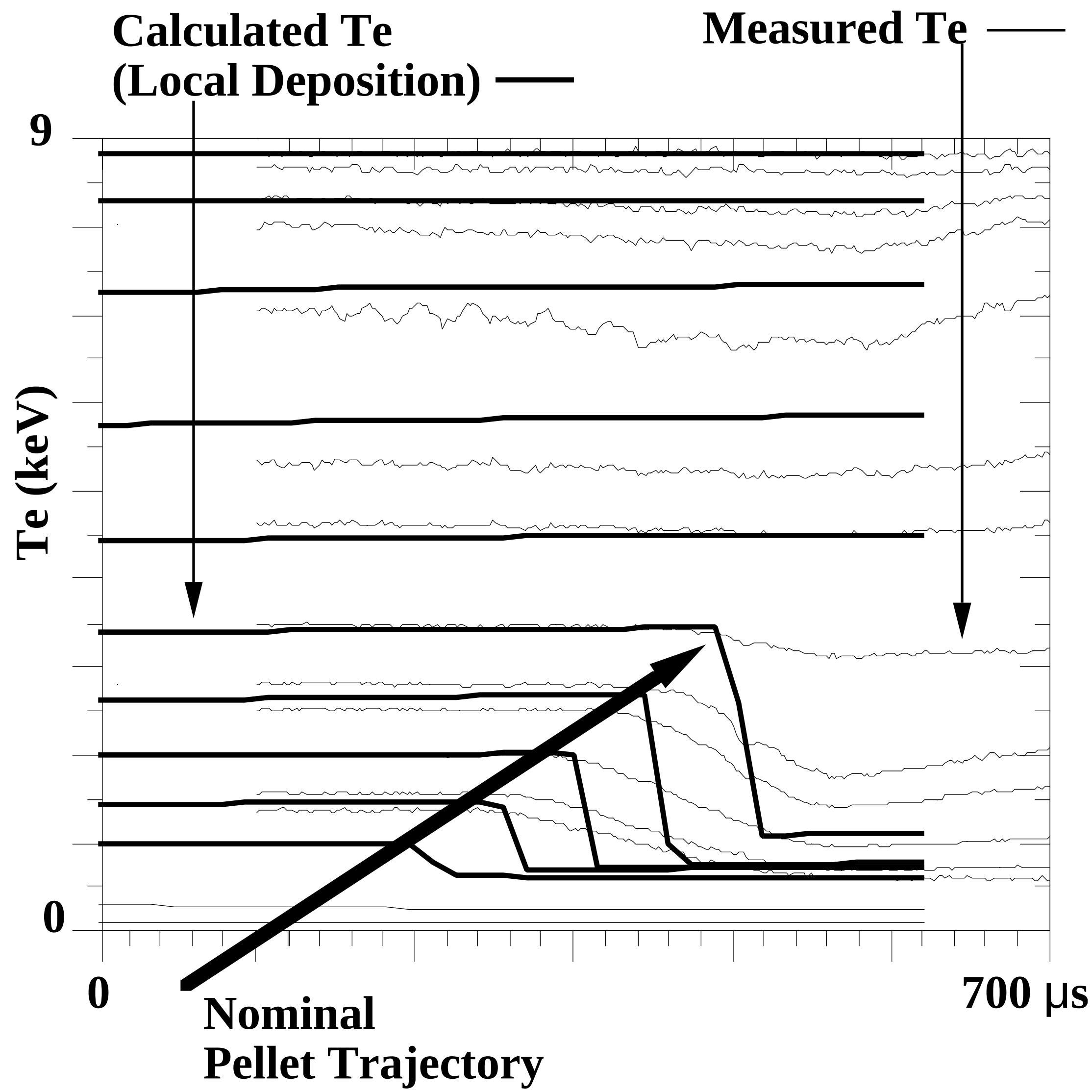
Mass is redistributed immediately without heating - redistribution ends when pellet is fully ablated

Allow some pellet mass to pass beyond the last closed flux surface and be lost

Amount of mass lost controlled by introducing a pseudo-volume outside last closed flux surface which is included in the mass redistribution - pseudo-volume chosen so that mass retained after pellet ablation is complete matches measured retained mass

Local Deposition with no mass redistribution predicts large drop in Te as pellet crosses flux tube - NOT consistent with experiment

Measured electron temperature behaviordoes not match rapid drop predicted by local deposition model neglecting mass redistribution



Simple Redistribution Model Reproduces Local Temperature Dilution Across Profile During Ablation Period

100% Redistribution / 80% Loss / Rp=2.0mm

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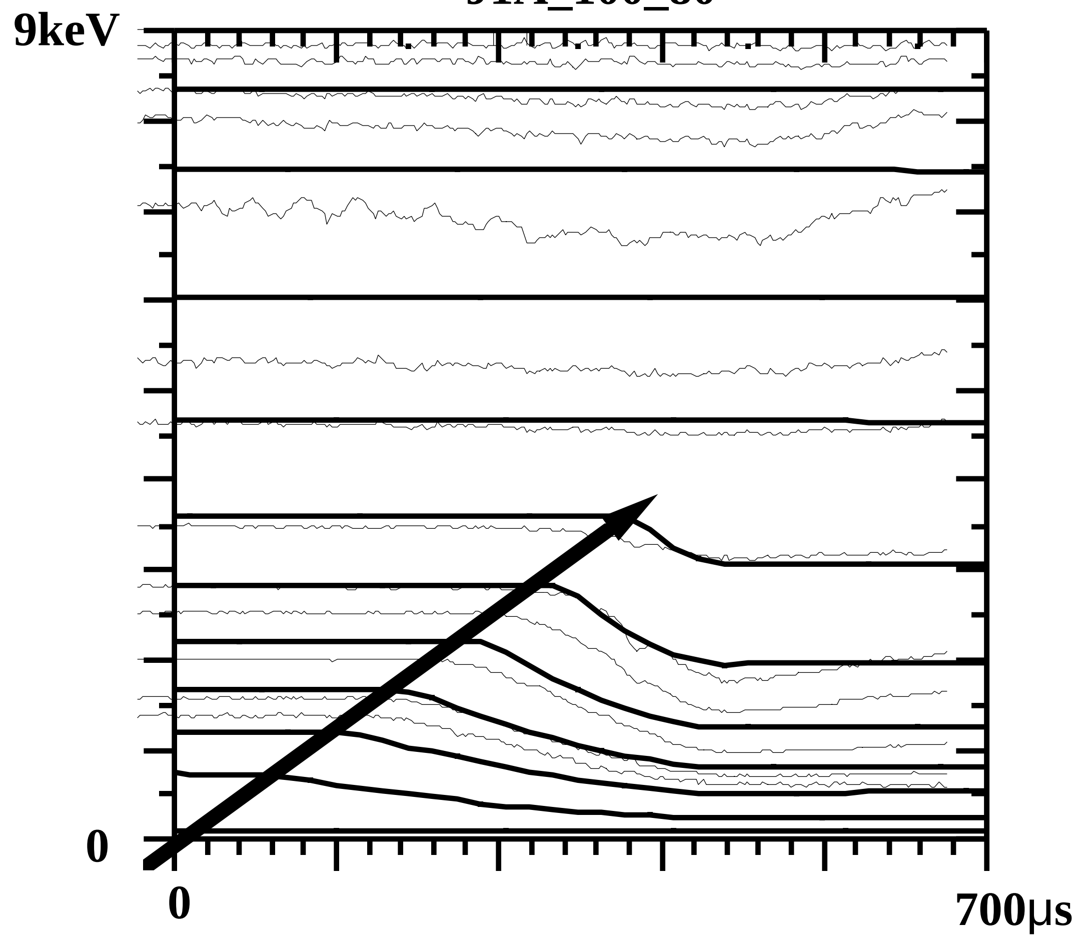


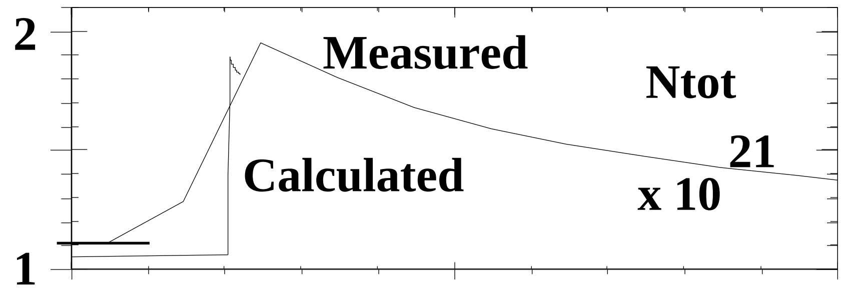
Simple model including mass redistribution matches Te measurement in detail.

Assumptions:

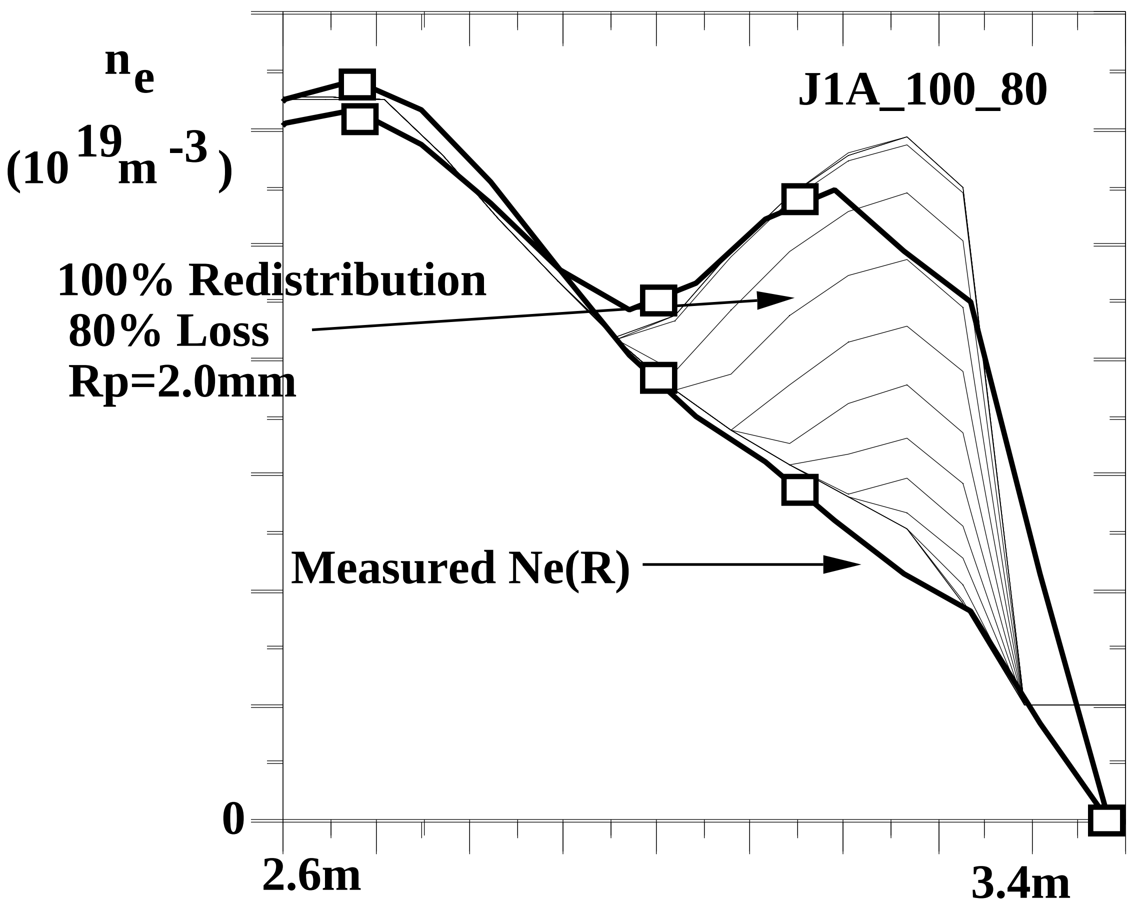
-Redistributed Mass Te << Local Te - Pellet Mass Thermalized only after redistribution ie ne * Te conserved

- pellet mass loss during redistribution matched to measured total density perturbation

Simple Model Reproduces Measured Deposition Profile



Simple Redistribution Model with 100% of local ablated pellet mass redistributed across plasma volume outside ablation radius and with an equivalent loss volume equal to 80% of the total plasma volume, also reproduces measured deposition profile



Conclusions:

ECE Measurements with High Time Resolution can be used to study the pellet mass redistribution

Radial mass redistribution appears to operate only during the period of pellet ablations

For the case of injection from the low field side, the redistribution mechanism appears too extend across the plasma outward from the ablating pellet to the plasma edge

The loss of pellet mass which is associated with reduced pellet fuelling efficiency can be consistent with the redistribution mechanism