

DEUTERIUM-TRITIUM TFTR PLASMAS IN THE HIGH POLOIDAL BETA REGIME

BY

S.A. SABBAGH, M.E. MAUEL, G.A. NAVRATIL, ET AL.

To be published in the Proceedings of the 15th International Atomic Energy Agency Conference on *Plasma Physics and Controlled Nuclear Fusion Research 1994* (September 26-October 1, 1994, Seville, Spain), to be published by IAEA, Vienna, 1995.

IAEA-CN-60/A-5-I-6
DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Work supported by U.S. Department of Energy Contracts
DE-FG02-89ER53297, DE-AC02-76CH0-3073, and DE-
FG02-90ER54084

MASTER

Princeton University
Plasma Physics Laboratory

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DEUTERIUM-TRITIUM TFTR PLASMAS IN THE HIGH POLOIDAL BETA REGIME*

S. A. Sabbagh[†], M. E. Mauel, G. A. Navratil
*Department of Applied Physics, Columbia University,
New York, NY USA*

M. G. Bell, C. E. Bush, R. V. Budny, D. S. Darrow, E. D. Fredrickson,
B. Grek, R. J. Hawryluk, H. W. Herrmann, A. Janos, D. W. Johnson,
L. C. Johnson, B. LeBlanc, D. K. Mansfield, D. C. McCune,
K. M. McGuire, D. Mueller, D. K. Owens, H. K. Park,
A. T. Ramsey, C. Skinner, E. J. Synakowski, G. Taylor,
R. M. Wieland, M. C. Zarnstorff, S. J. Zweben
Princeton Plasma Physics Laboratory, Princeton, NJ USA

S. H. Batha, F. M. Levinton
Fusion Physics and Technology, Inc., Torrance, CA USA

S. P. Hirshman, D. A. Spong
Oak Ridge National Laboratory, Oak Ridge, TN USA

J. Kesner
Plasma Fusion Center, M.I.T., Cambridge, MA USA

ABSTRACT

Deuterium-tritium plasmas with enhanced energy confinement and stability have been produced in the high poloidal beta, advanced tokamak regime in TFTR. Confinement enhancement $H \equiv \tau_E / \tau_{E \text{ ITER-89P}} > 4$ has been obtained in a limiter H-mode configuration at moderate plasma current $I_p = 0.85 - 1.46$ MA. By peaking the plasma current profile, $\beta_N \text{ dia} \equiv 10^8 < \beta_{t1} > aB_0 / I_p = 3$ has been obtained in these plasmas, exceeding the β_N limit for TFTR plasmas with lower internal inductance, l_i . Fusion power exceeding 6.7 MW with a fusion power gain $Q_{DT} = 0.22$ has been produced with reduced alpha particle first orbit loss provided by the increased l_i .

I. Introduction

The economics of a fusion power plant based on the tokamak concept can be significantly improved if the plasma stability and energy confinement, usually parameterized by the Troyon normalized beta [1], $\beta_N \equiv 10^8 < \beta_{t1} > aB_0 / I_p$, and energy confinement enhancement factor [2], $H \equiv \tau_E / \tau_{E \text{ ITER-89P}}$, could be

enhanced. Present reactor design studies [3] show that 50% reductions in the cost of electricity and the capital cost of the plant can be obtained with "advanced tokamak" operation at high $H \leq 4$ and $\beta_N \leq 6$ compared to more conventional tokamak operating parameters. Advanced tokamak plasmas in steady-state operation have been considered in both the ARIES [4] and SSTR [5] designs.

Operation at high poloidal beta, β_p , has the additional benefit of reduced plasma current, I_p , which reduces the requirements for non-inductive current drive, increases the fraction of transport-induced bootstrap current, and reduces the adverse consequences of disruptions. The advantages of this operating regime have been understood for some time and large experimental tokamak programs including TFTR [6], JT-60U [7], and DIII-D [8] have produced and studied high β_p plasmas. Operation at high H and β_N has been achieved by modifying the plasma current and pressure profiles [6, 9-10], and the shape of the outer boundary [11-12].

Prior to the use of deuterium and tritium (DT) in TFTR, high β_p *dia* = 5.9 (up to the equilibrium limit [13]), β_N *dia* = 4.9, $H \equiv \tau_E/\tau_{E\text{ ITER-89P}} = 3.6$ (with β_N *dia* = 4.5, $H = 3.5$ reached simultaneously) conditions had been obtained in deuterium (D) plasmas at $I_p < 0.5$ MA by actively peaking the current profile and creating a plasma with increased internal inductance, l_i [6]. Here, β_p *dia* $\equiv 2\mu_0 \langle p_\perp \rangle / \langle \langle B_p \rangle \rangle^2$ where $\langle p_\perp \rangle$ is the volume averaged transverse plasma pressure and $\langle \langle B_p \rangle \rangle$ is the line average of the poloidal magnetic field over the outer flux surface. In addition, high β_p plasmas with an on-axis safety factor, $q_0 > 2$, and low magnetic field shear in the core had been created with access to the second stability region [14]. Recently, a separate set of experiments has produced plasmas with high q_0 exhibiting a reversal in the magnetic field shear and enhanced confinement properties [15]. Similar "high l_i " and "high q_0 " operating scenarios are planned to be produced and studied under steady-state plasma conditions in the proposed Tokamak Physics Experiment [16].

The experiments described in this paper are the first to utilize nominally equal concentrations of D and T in high poloidal beta plasmas in TFTR with current and density profiles optimized for high β_N and high H . The purpose of these experiments is to demonstrate the ability to produce significant levels of fusion power with these plasmas and to examine the characteristics of these discharges in the presence of DT fusion alpha particles. Both "high l_i " and "moderate q_0 " ($1 \leq q_0 \leq 1.5$) operating scenarios are considered in the present study.

The ability of high β_p plasmas to generate significant levels of fusion power at reduced plasma current is illustrated in Fig. 1. Here, the peak DT fusion power, P_F , is plotted as a function of I_p for TFTR supershot plasmas with $I_p \geq 1.5$ MA and high β_p plasmas at lower I_p . Up to 6.7 MW of fusion power was produced in a non-disruptive high β_p plasma with auxiliary heating power $P_{tot} = 31$ MW, $I_p = 1.46$ MA, and $q^* \equiv 5(a^2 B_0 / R_p I_p (\text{MA})) (1 + \kappa^2) / 2 = 4.7$. This value of q^* is in the range presently being considered in advanced tokamak reactor design studies. The fraction of fusion reactions by thermal ion collisions, beam ion collisions with other beam ions, and beam ion collisions with thermal ions, as computed by the TRANSP code [17] were 34%, 10%, and 56%, respectively. This level of fusion power is 90% of the maximum power produced in a non-disruptive supershot plasma, but at 2/3 of the plasma current.

II. Experimental parameters

The increase in I_i required to produce high β_N plasmas in TFTR was produced by rapidly decreasing the plasma current from $I_p = 1.65 - 2.5$ MA to $0.85 - 1.46$ MA in a deuterium plasma with toroidal field $B_t = 4.6 - 5.1$ T and major radius $R_p = 2.45 - 2.6$ m during a period of neutral beam injection (NBI) in the co-direction (Fig. 2a). Addition of counter-injected beams later in the discharge produced the desired power level $P_{tot} = 16 - 31$ MW with a nominally equal number of D and T sources. The fraction of P_{tot} due to injected tritium neutral beam power was in the range $0.45 - 0.72$. Electron and ion temperatures reached 11 keV and 35 keV respectively with peak electron densities of up to $8 \times 10^{19} \text{ m}^{-3}$. Non-inductive current of up to 55% has been computed by TRANSP at $I_p = 1.46$ MA with a 35% contribution from the bootstrap current. The thermal plasma comprised 65% of the total stored energy in the highest density plasmas. Determination of the q profile using motional Stark effect (MSE) measurements of the magnetic field pitch angle indicate that $q_0 \leq 1$ for plasmas with $I_p \geq 1$ MA.

High β_p DT plasmas with moderate q_0 , $I_p = 0.85$ MA, $R_p = 2.6$ m, and $P_{tot} \leq 17$ MW were produced in a manner similar to that described above to test the recent theoretical result [18] indicating that the alpha particle driven toroidal Alfvén eigenmode (TAE) [19] can be destabilized if q_0 could be raised to a value between 1.2 and 1.5 . In this case, $\beta_{p \text{ dia}} = 2.9$, $\beta_{N \text{ dia}} = 2.8$, $H = 4.2$, and $P_F = 1.8$ MW were attained and preliminary equilibrium modelling using MSE data shows $q_0 = 1.4$.

Advanced tokamak operation in DT produced a relatively large alpha particle beta, β_α , for a given plasma current. The on-axis value, $\beta_{\alpha 0}$, of 1.6×10^{-3} was computed by TRANSP for the $I_p = 1.2$ MA DT plasma shown in Fig. 2. This value is the same as has been obtained in a DT supershot plasma with $I_p = 1.8$ MA. At $I_p = 1.2$ MA, the β_α profile is slightly broader. A $\beta_{\alpha 0}$ of 2.5×10^{-3} was generated in the plasma with $P_F = 6.7$ MW. The plasma at moderate q_0 had a peak $\beta_{\alpha 0} = 0.9 \times 10^{-3}$.

III. Enhanced confinement and the DT limiter H-mode

Producing enhanced energy confinement involved a reduction in particle recycling. This was obtained in both D and DT plasmas when the discharge made a transition to a limiter H-mode [20], or by lithium pellet conditioning [21] of the limiter. Limiter conditioning has allowed τ_E at $I_p > 1$ MA to reach a value of 0.2 s at 1.5 MA. This is a significant improvement compared to the maximum value of $\tau_E = 0.14$ s reached before the use of Li pellets in high β_p plasmas [22]. Similar increases in τ_E have been observed in sequences of D plasmas which utilize Li conditioning before and/or after NBI. The greatest improvements were obtained when pellets were injected before NBI. The combination of limiter conditioning, operation using DT, and transition to a limiter H-mode has produced a maximum value of $\tau_E = 0.26$ s.

The general characteristics of edge localized modes (ELMs), precursor MHD activity to β -collapse, and disruptions are similar in D and DT plasmas. High frequency "grassy" ELMs occur in low power H-mode discharges, while large amplitude, low frequency (~ 40 Hz in Fig. 2) "giant" ELMs are more likely to occur

in DT plasmas with relatively broad pressure profiles and high β_N . DT H-mode plasmas exhibit an earlier transition time, a longer ELM-free phase, and a greater drop in D_α light when compared to equivalent D plasmas.

Transitions to the high β_p H-mode in equivalent D and DT plasmas are shown in Fig. 2 (c-e). While a significant increase in τ_E was observed in the D plasma during the MHD quiescent "ELM-free" phase of the H-mode, a greater increase (of approximately 40%) was observed in the DT plasma [23] and an H factor of 4.3 (using an average isotopic mass of 2.3) was attained. This improvement was transient, since the onset of the first ELM caused a decrease in τ_E . However, a recovery of enhanced energy confinement was observed during the relaxation period of the ELMs.

Since transition to the H-mode occurred during the initial rise of the plasma stored energy during NBI, the plasma density and temperature increased up to the onset time of the first ELM. However, while the edge electron temperature and density steadily increased, the edge T_i displayed a more rapid increase in both DT and D plasmas at the time of the H-mode transition (Fig. 2(e)). At this time, the effective ion thermal diffusivity, $\chi_{i\ tot} \equiv -q_i/n_{i\ th} \nabla T_i$ as computed by TRANSP decreased in both DT and D comparison plasmas (Fig. 3). Here, q_i is the ion heat flux, and $n_{i\ th}$ is the thermal ion density. A larger change in T_i and $\chi_{i\ tot}$ occurred in DT plasmas as compared to equivalent D discharges.

After the onset of ELMs, the increase in both the edge temperature and density ceased. The edge T_e decreased during an ELM burst but recovered its original value before the next ELM burst. In addition, the edge T_i in DT plasmas decreased to the value reached in the equivalent D plasma. This matching of the T_i profile, which appeared to be caused by the ELMs, generally extended from the plasma edge to a normalized minor radius $r/a = 0.65$.

The range of H and β_N achieved during the DT phase of TFTR operation is shown in Fig. 4. The highest values of H (up to 4.5) were reached transiently during the ELM-free H-mode phase, during which time $(dW_{tot}/dt)/P_{NBI}$ was maximized (exceeding 40% in some discharges). While the largest value of H occurred in a D plasma at $I_p = 1$ MA, DT plasmas produced the larger H at equal P_{tot} and I_p . Also indicated in Fig. 4 are the values of β_N and H for some plasmas at the time of maximum β_N (where $dW_{tot}/dt = 0$). The high β_p plasma with the highest fusion power output, $P_F = 6.7$ MW reached during the ELMing phase of the discharge, had $H = 3.1$ and $\beta_{N\ dia} = 3$.

IV. Stability

Plasma stability limited the improvement in τ_E for plasmas with high H factor. The first high β_p DT experiments were concentrated on reaching enhanced performance while simultaneously minimizing the probability of major disruptions. Based on results from prior D plasma operation, the $\beta_{N\ dia}$ stability limit was determined for a given plasma current time history, and a value of $\beta_{N\ dia}$ 15% below this limit was chosen as a target value for DT operation. This technique was almost entirely successful. Out of 134 discharges in which neutral beams were injected, only 3 major disruptions were produced, each one occurring below the reduced target value of $\beta_{N\ dia}$. Two of these disruptions occurred in D plasmas for which the electron density profile peakedness, $F_{N_e} \equiv n_e(0)/\langle n_e \rangle_{volume}$ became

excessively large. This observation of a reduced β_N limit at increased density peakedness is consistent with ideal MHD stability analyses of $n = 1$ kink/ballooning modes performed for TFTR deuterium plasmas [22]. The result of these calculations showed that the increase in $\beta_{N\text{ dia}}$ observed in plasmas with increased internal inductance can be eliminated by increased peaking of the plasma pressure profile. The excessive density peaking was created by excessive limiter conditioning using Li. This conditioning typically caused a reduction of particle recycling that allowed increased neutral beam penetration and caused F_{N_e} to rise (with a corresponding increase in τ_E). The disruptions that occurred below the target value of $\beta_{N\text{ dia}}$ had $F_{N_e} = 3.4$, while a more common value for high β_p plasmas is 2.5.

The peakedness of the DT neutron source strength as measured with a neutron collimator (an indicator of the pressure profile peakedness) was found to be a useful diagnostic in examining the MHD stability. DT plasmas either disrupted or suffered a β -collapse when the neutron profile peakedness rapidly increased to a value of $P_{SN} \equiv S_N(0)/\langle S_N \rangle_{\text{volume}} \sim 10$ (Fig. 5). Such large values of P_{SN} were obtained only with DT operation or Li pellet injection. These β -limiting events occurred at β_N less than the observed disruptive limit of D plasmas with less peaked pressure profiles.

A "secondary ballooning instability" [24] was clearly observed as a precursor to the DT disruption and the toroidally localized nature of this mode was established by observing T_e fluctuations at two distinct toroidal locations. Details of this instability can be found in a companion paper by Fredrickson, *et al.* [25].

Alpha-driven TAE instabilities have not yet been observed in high β_p DT plasmas. TAE mode stability analysis of plasmas with high l_i and $q_0 \leq 1$ is consistent with this observation. The $\beta_{\alpha 0}$ required to drive the least stable toroidal mode number, n , was computed to be 9.0×10^{-3} for the $n = 4$ mode in the DT plasma shown in Fig. 2. This level is 5.6 times greater than the peak $\beta_{\alpha 0}$ reached in this discharge. High β_p plasmas at moderate q_0 that were also observed to be stable are computed to be stable, but have $\beta_{\alpha 0}$ significantly closer to the unstable boundary. Preliminary analysis of the DT plasma with $q_0 = 1.4$ yields an instability threshold of $\beta_{\alpha 0} = 2.1 \times 10^{-3}$ for the $n = 1$ mode, which is a factor of 2.2 larger than the peak $\beta_{\alpha 0}$ generated in this discharge.

V. Alpha Particle Confinement

Confinement of alpha particles in high poloidal beta plasmas appears to be classical and large losses due to collective effects have not been observed. The alpha particle loss fraction does not increase as the fusion reactivity increases (Fig. 6). High poloidal beta plasmas with $I_p = 1.5$ MA and higher plasma internal inductance experience alpha loss similar to 2.0 MA supershot plasmas with a lower plasma internal inductance. Due to the peaked current profile produced in the high β_p plasmas, first orbit losses are less than in a plasma with lower l_i and equal I_p . Modelling of experimental DT plasmas using TRANSP shows that at $I_p = 1$ MA, 17% of the alpha particles are lost with $l_i = 2.2$ as opposed to 34% with $l_i = 1.2$.

The ELMs also have a small but measurable effect on the DT fusion alpha particle loss. The alpha particle detector mounted at a poloidal position 90° below the outboard midplane of the torus measured a fluctuation in amplitude of less than

10%, approximately in phase with the ELM bursts. The detector mounted at 45° below the outboard midplane showed a 15% fluctuation that was out of phase with the ELM bursts. This modest poloidal redistribution of particle loss may be important for ITER, in which even a few percent loss of the alpha particle population could damage first wall components.

VI. Conclusion

The initial TFTR DT experiments performed in the high β_p "advanced tokamak" regime have begun to address issues important to future tokamak reactors designed to operate in this regime. Significant fusion power production (6.7 MW) has been demonstrated at $\beta_{N\,dia} = 3$, $H = 3.1$, and $q^* = 4.7$ with a central fusion power density (1.6 MW/m^3) at the level of the present ITER design (1.7 MW/m^3). In these plasmas, peaking the current profile allowed fusion power production similar to supershot plasmas, but at $2/3$ of the plasma current. Operation with DT produced an increase in τ_E of approximately 40% in an enhanced limiter H-mode. Confinement of alpha particles was classical, with no large loss due to collective effects. Alpha particle losses due to ELMs are small, but are at a level that may be significant to the operation of ITER. The alpha particle driven TAE has not been observed to date in these plasmas. DT plasmas with high l_i and $q_0 \leq 1$ are computed to have an adequate margin against TAE instability. However, plasmas at moderate q_0 might encounter TAE instability at higher P_{tot} since TFTR DT plasmas are presently about a factor of two below the computed instability boundary. Future experiments are planned to test the TAE thresholds at $q_0 \sim 1.4$ by increasing $\beta_{\alpha 0}$ in these plasmas.

* Supported by US DoE Contracts DE-FG02-89ER53297, DE-AC02-76-CH03073, and DE-FG02-90ER54084.

† Present address: Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ 08543, USA

- [1] F. Troyon, *et al.*, Phys. Lett. **110A** (1985) 29.
- [2] P. N. Yushmanov, *et al.*, Nuclear Fusion **30** (1990) 1999.
- [3] R. J. Goldston, *et al.*, European Physical Society Meeting, Montpellier, June 1994, and references therein; L. J. Perkins, *et al.*, submitted to Nuclear Fusion.
- [4] F. Najmabadi, *et al.*, in Proceedings of the 13th International Symposium on Fusion Engineering, Knoxville (1989) 1021.
- [5] M. Kikuchi, *et al.*, Nuclear Fusion **30** (1991) 265.
- [6] S. A. Sabbagh, *et al.*, Phys. Fluids B **3** (1991) 2277.
- [7] S. Ishida, *et al.*, Plasma Phys. and Contr. Nucl. Fus. Res., **1** (1993) 219.
- [8] P. Politzer, *et al.*, Phys. Plasmas **1** (1994) 1545.
- [9] J. R. Ferron, *et al.*, Phys. Fluids B **5** (1993) 2532.
- [10] Y. Kamada, *et al.*, "Noninductively Current Driven H-mode with High and High values in JT-60U", submitted to Nucl. Fusion.
- [11] G. A. Navratil, *et al.*, Plasma Phys. and Contr. Nucl. Fus. Res., **1** (1991) 209.
- [12] L. L. Lao, *et al.*, Phys. Rev. Lett. **70** (1993) 3435.
- [13] M. E. Mauel, *et al.*, Nuclear Fusion **32** (1992) 1468.
- [14] S. A. Sabbagh, *et al.*, Bull. Am. Phys. Soc. **38** (1993) 1984.

-
- [15] F. M. Levinton, *et al.*, Americal Physical Society Division of Plasma Physics meeting (1994); R. J. Goldston, *et al.*, European Physical Society Meeting, Montpellier, June 1994.
 - [16] G. H. Neilson, *et al.*, in Proceedings of the 11th Topical Meeting on the Technology of Fusion Energy, 1994, to be published in Fusion Technology.
 - [17] R. J. Goldston, *et al.*, J. Comput. Phys. **43** (1981) 61.
 - [18] D. A. Spong, *et al.*, these proceedings, paper IAEA-CN-60/D-P-II-3.
 - [19] C. Z. Cheng, *et al.*, Ann. Phys. **161** (1985) 21.
 - [20] C. E. Bush, *et al.*, Phys. Rev. Lett. **65** (1990) 424.
 - [21] J. Snipes, *et al.*, J. Nucl. Mater. **196-198** (1992) 686.
 - [22] M. E. Mauel, *et al.*, Plasma Phys. Contr. Nucl. Fus. Res., **1** (1993) 205.
 - [23] C. E. Bush, *et al.*, 21st EPS Conference on Controlled Fusion and Plasma Physics, Montpellier, 1994.
 - [24] Y. Nagayama, S. A. Sabbagh, J. Manickam, *et al.*, Phys. Rev. Lett. **69** (1992) 2376; M. N. Bussac and R. Pellat, Phys. Rev. Lett. **59** (1987) 2650.
 - [25] E. D. Fredrickson, *et al.*, these proceedings, paper A-2-II-5.

Figure Captions

Fig. 1. DT fusion power vs. plasma current for TFTR high β_p and supershot plasmas

Fig. 2. Time history waveforms for a high β_p DT H-mode plasma and comparison to an equivalent D discharge. Shown in this figure are a) the plasma current, plasma internal inductance, and neutral beam heating, b) diamagnetic normalized beta and DT fusion power c) Energy confinement enhancement factor and confinement time, d) D_α emission, e) edge ion temperature.

Fig. 3. Reduction in $\chi_{i\ tot}$ for the DT and D plasmas shown in Fig. 2 before the H-mode transition and during the ELM-free H-mode phase. The largest change was observed during the ELM-free phase of DT H-mode plasmas at a normalized minor radius $r/a \geq 0.5$.

Fig. 4. Range of β_N and H reached by high β_p plasmas during the DT phase. The different symbols indicate varying I_p . The majority of the data shown was taken at the time of peak H . The data shown by the arrow was taken at the time of peak β_N . Solid or bold symbols indicate a plasma in which DT was used. None of the plasmas represented terminated in disruption.

Fig. 5. Time evolution of DT neutron peakedness in plasmas of varying MHD stability. Plasma with $P_{SN} \sim 10$ encountered major and minor disruptions at reduced $\beta_{N\ dia}$. Plasmas with lower peakedness were stable at greater than 90% of the anticipated $\beta_{N\ dia}$ limit.

Fig. 6. Alpha particle loss as a function of DT neutron reactivity in high performance TFTR plasma regimes.

Fig. 1

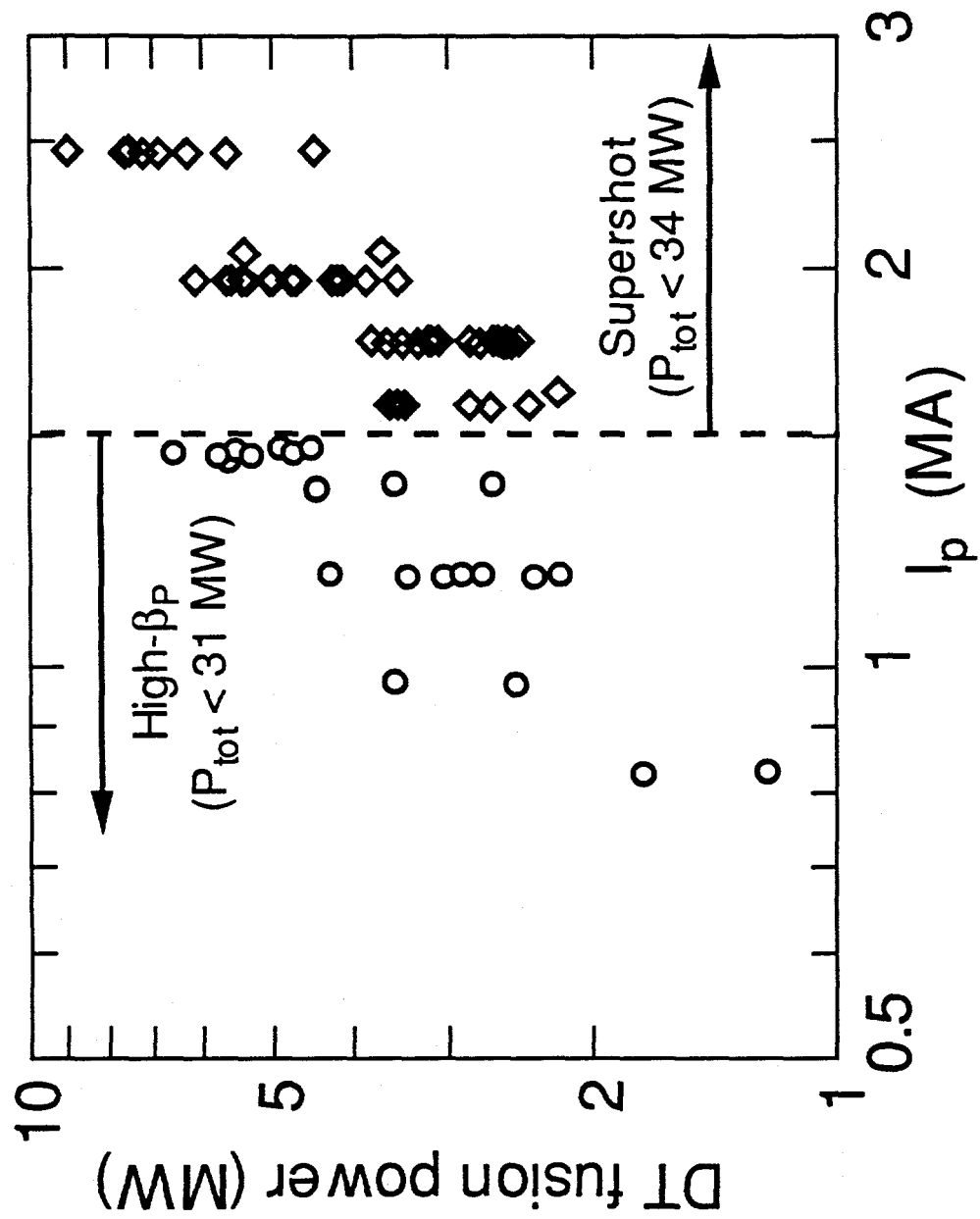


Fig. 2

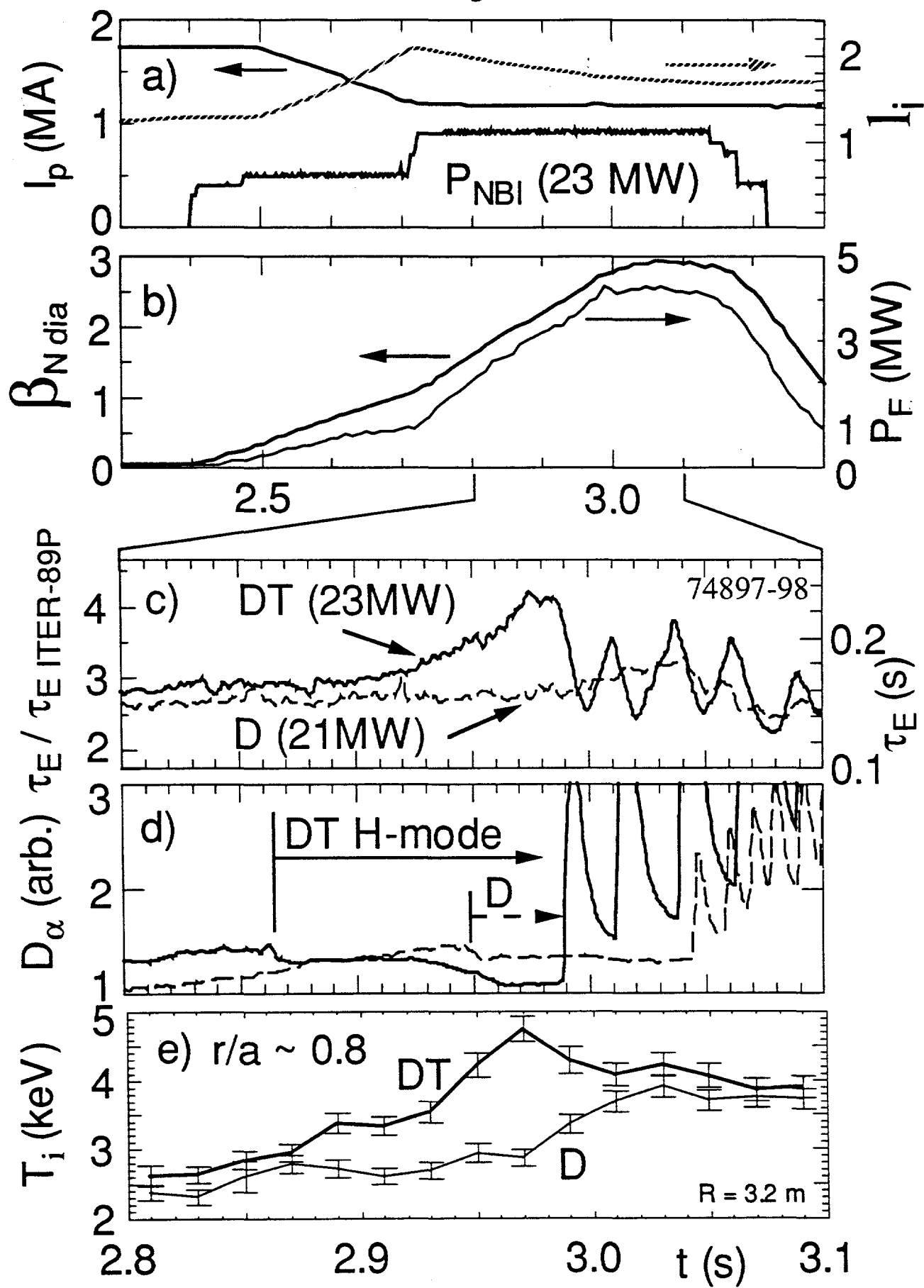


Fig. 3

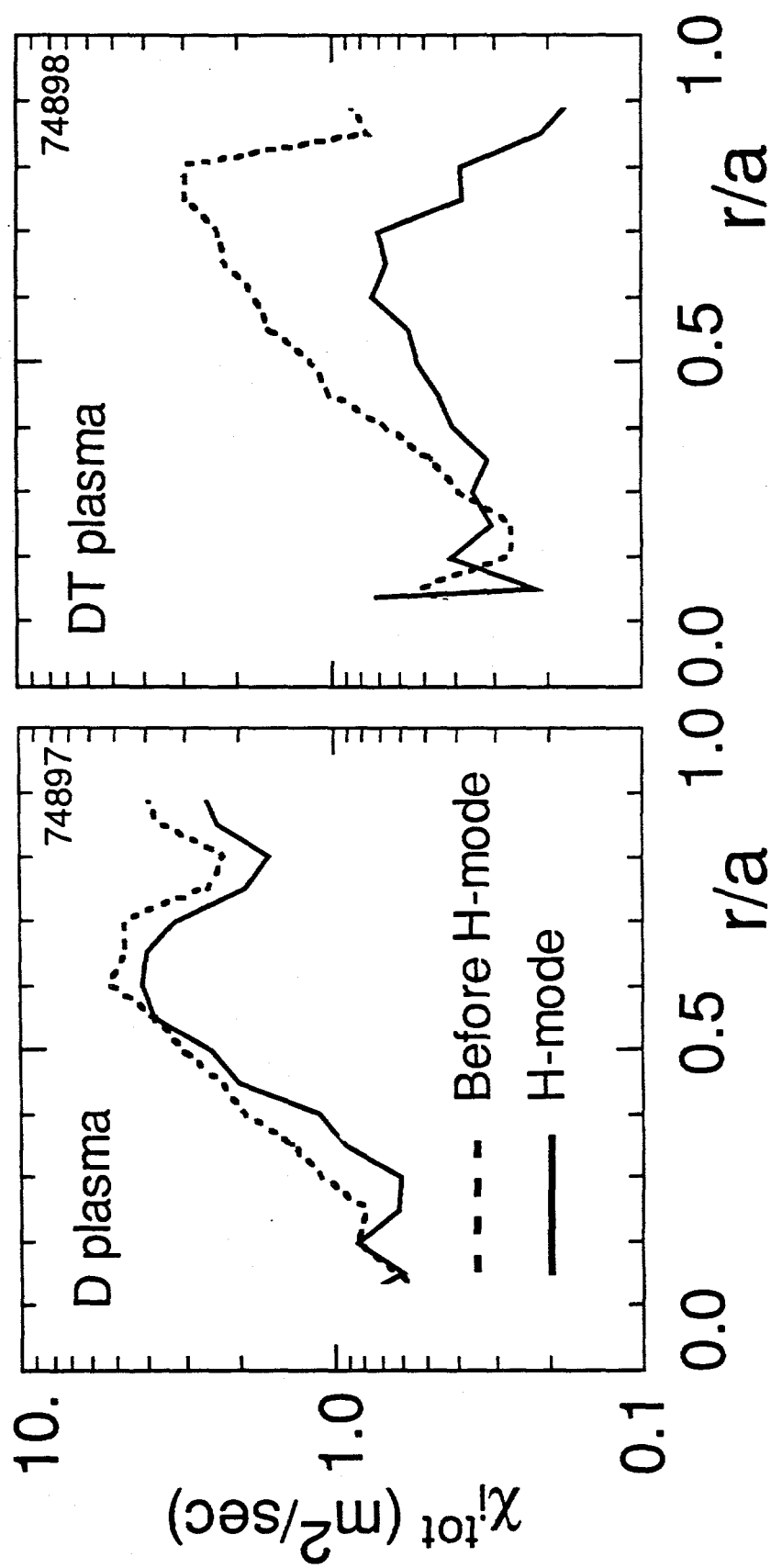


Fig. 4

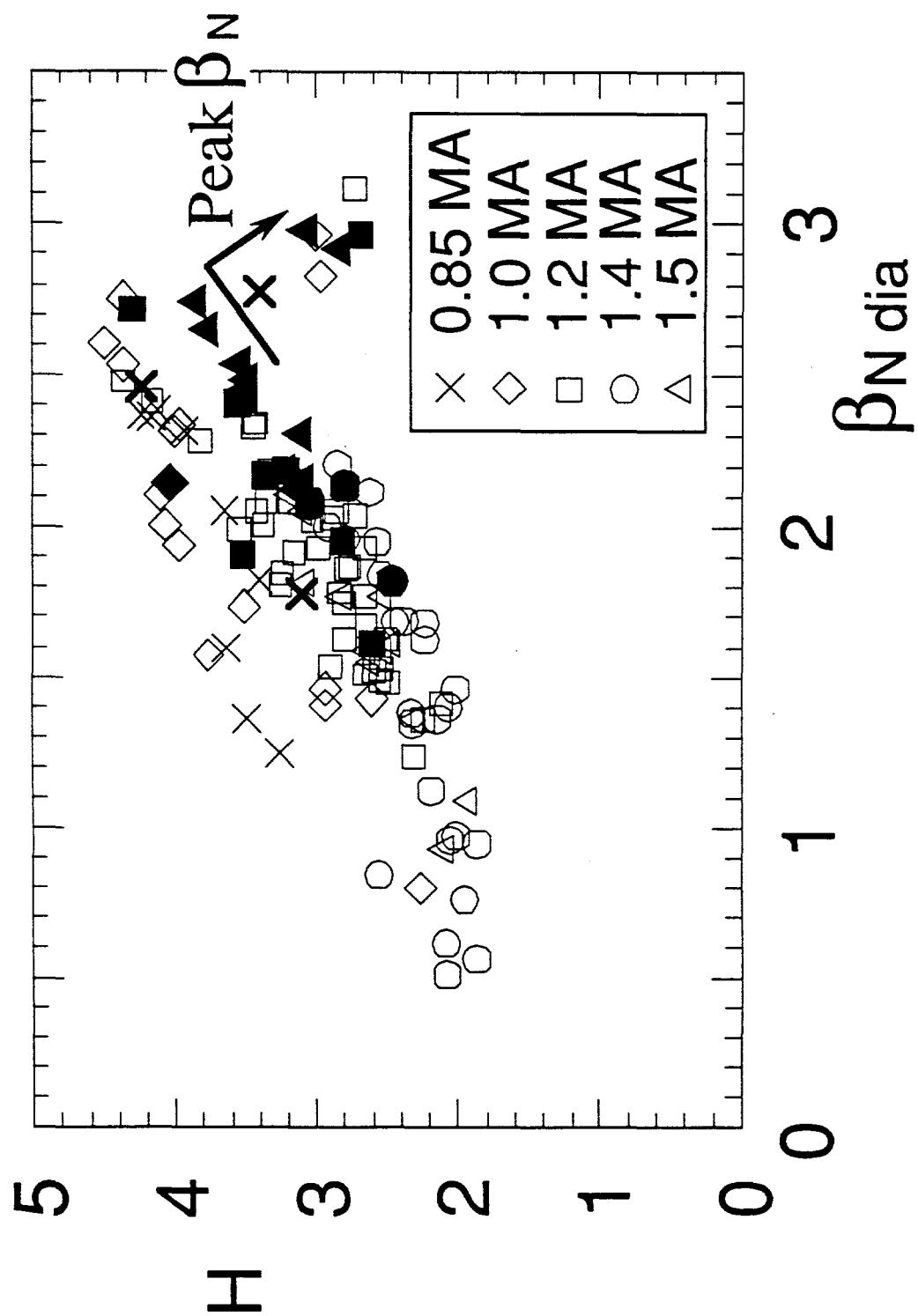


Fig. 5

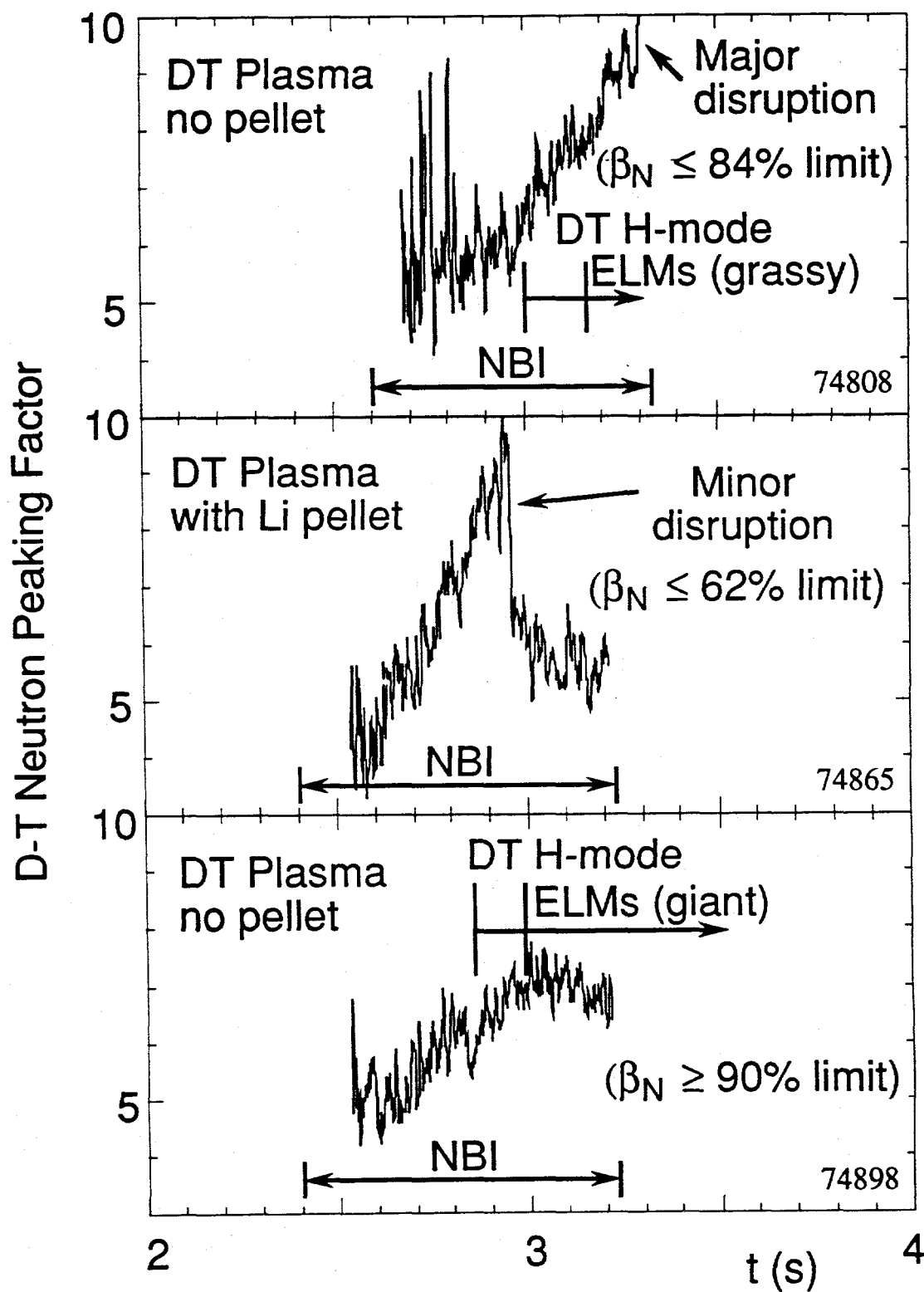
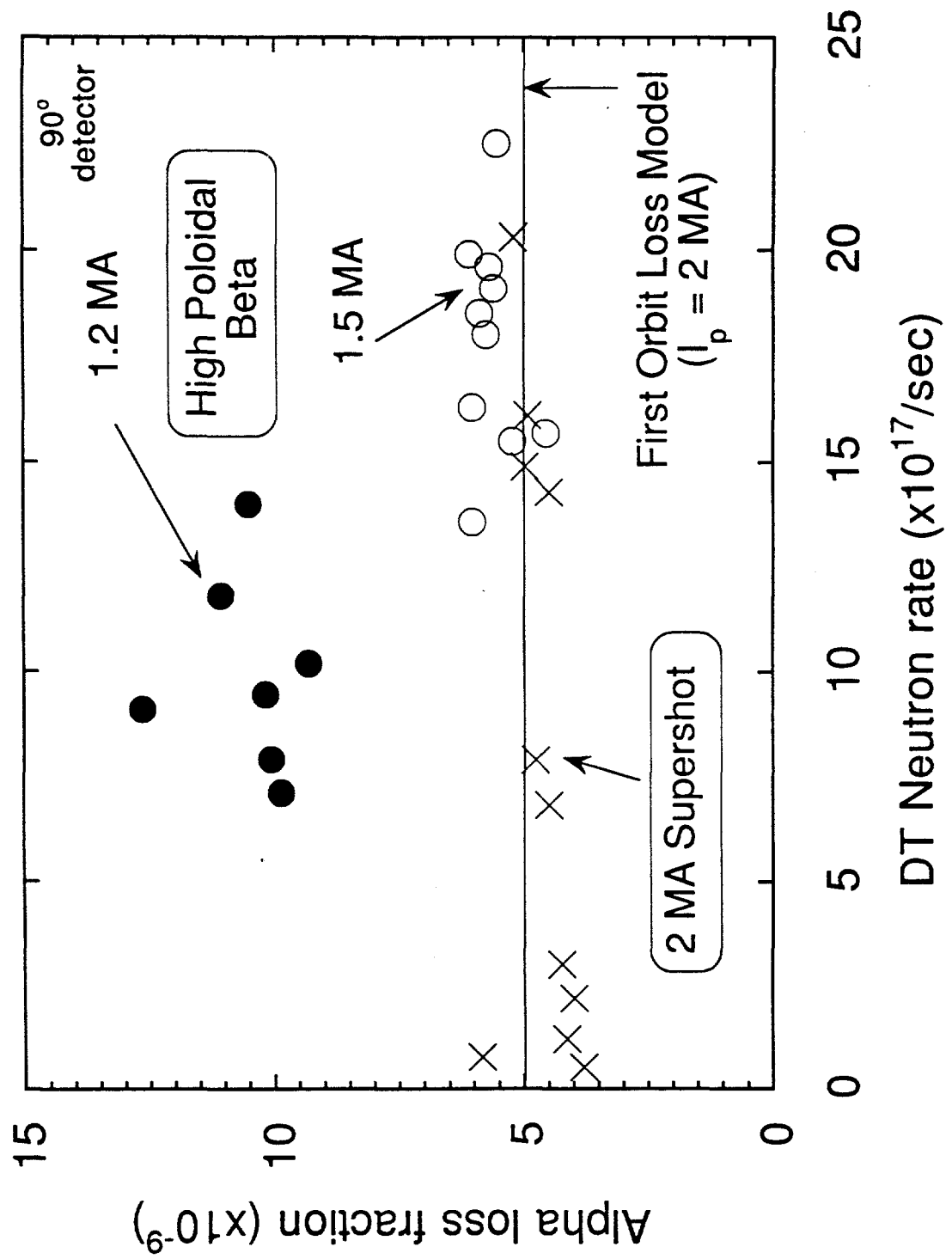


Fig. 6



EXTERNAL DISTRIBUTION IN ADDITION TO UC-420

Dr. F. Paoloni, Univ. of Wollongong, AUSTRALIA
 Prof. R.C. Cross, Univ. of Sydney, AUSTRALIA
 Plasma Research Lab., Australian Nat. Univ., AUSTRALIA
 Prof. I.R. Jones, Flinders Univ, AUSTRALIA
 Prof. F. Cap, Inst. for Theoretical Physics, AUSTRIA
 Prof. M. Heindler, Institut für Theoretische Physik, AUSTRIA
 Prof. M. Goossens, Astronomisch Instituut, BELGIUM
 Ecole Royale Militaire, Lab. de Phy. Plasmas, BELGIUM
 Commission-European, DG. XII-Fusion Prog., BELGIUM
 Prof. R. Bouciqué, Rijksuniversiteit Gent, BELGIUM
 Dr. P.H. Sakanaka, Instituto Fisica, BRAZIL
 Prof. Dr. I.C. Nascimento, Instituto Fisica, Sao Paulo, BRAZIL
 Instituto Nacional De Pesquisas Espaciais-INPE, BRAZIL
 Documents Office, Atomic Energy of Canada Ltd., CANADA
 Ms. M. Morin, CCFM/Tokamak de Varennes, CANADA
 Dr. M.P. Bachynski, MPB Technologies, Inc., CANADA
 Dr. H.M. Skarsgard, Univ. of Saskatchewan, CANADA
 Prof. J. Teichmann, Univ. of Montreal, CANADA
 Prof. S.R. Sreenivasan, Univ. of Calgary, CANADA
 Prof. T.W. Johnston, INRS-Energie, CANADA
 Dr. R. Bolton, Centre canadien de fusion magnétique, CANADA
 Dr. C.R. James,, Univ. of Alberta, CANADA
 Dr. P. Lukác, Komenského Universzita, CZECHO-SLOVAKIA
 The Librarian, Culham Laboratory, ENGLAND
 Library, R61, Rutherford Appleton Laboratory, ENGLAND
 Mrs. S.A. Hutchinson, JET Library, ENGLAND
 Dr. S.C. Sharma, Univ. of South Pacific, FIJI ISLANDS
 P. Mähönen, Univ. of Helsinki, FINLAND
 Prof. M.N. Bussac, Ecole Polytechnique,, FRANCE
 C. Mouttet, Lab. de Physique des Milieux Ionisés, FRANCE
 J. Radet, CEN/CADARACHE - Bat 506, FRANCE
 Prof. E. Economou, Univ. of Crete, GREECE
 Ms. C. Rinni, Univ. of Ioannina, GREECE
 Preprint Library, Hungarian Academy of Sci., HUNGARY
 Dr. B. DasGupta, Saha Inst. of Nuclear Physics, INDIA
 Dr. P. Kaw, Inst. for Plasma Research, INDIA
 Dr. P. Rosenau, Israel Inst. of Technology, ISRAEL
 Librarian, International Center for Theo Physics, ITALY
 Miss C. De Palo, Associazione EURATOM-ENEA, ITALY
 Dr. G. Grosso, Istituto di Fisica del Plasma, ITALY
 Prof. G. Rostangni, Istituto Gas Ionizzati Del Cnr, ITALY
 Dr. H. Yamato, Toshiba Res & Devel Center, JAPAN
 Prof. I. Kawakami, Hiroshima Univ., JAPAN
 Prof. K. Nishikawa, Hiroshima Univ., JAPAN
 Librarian, Naka Fusion Research Establishment, JAERI, JAPAN
 Director, Japan Atomic Energy Research Inst., JAPAN
 Prof. S. Itoh, Kyushu Univ., JAPAN
 Research Info. Ctr., National Inst. for Fusion Science, JAPAN
 Prof. S. Tanaka, Kyoto Univ., JAPAN
 Library, Kyoto Univ., JAPAN
 Prof. N. Inoue, Univ. of Tokyo, JAPAN
 Secretary, Plasma Section, Electrotechnical Lab., JAPAN
 Dr. O. Mitarai, Kumamoto Inst. of Technology, JAPAN
 Dr. G.S. Lee, Korea Basic Sci. Ctr., KOREA
 J. Hyeon-Sook, Korea Atomic Energy Research Inst., KOREA
 D.I. Choi, The Korea Adv. Inst. of Sci. & Tech., KOREA
 Prof. B.S. Liley, Univ. of Waikato, NEW ZEALAND
 Inst of Physics, Chinese Acad Sci PEOPLE'S REP. OF CHINA
 Library, Inst. of Plasma Physics, PEOPLE'S REP. OF CHINA
 Tsinghua Univ. Library, PEOPLE'S REPUBLIC OF CHINA
 Z. Li, S.W. Inst Physics, PEOPLE'S REPUBLIC OF CHINA
 Prof. J.A.C. Cabral, Instituto Superior Tecnico, PORTUGAL
 Prof. M.A. Hellberg, Univ. of Natal, S. AFRICA
 Prof. D.E. Kim, Pohang Inst. of Sci. & Tech., SO. KOREA
 Prof. C.I.E.M.A.T, Fusion Division Library, SPAIN
 Dr. L. Stenflo, Univ. of UMEA, SWEDEN
 Library, Royal Inst. of Technology, SWEDEN
 Prof. H. Wilhelmson, Chalmers Univ. of Tech., SWEDEN
 Centre Phys. Des Plasmas, Ecole Polytech, SWITZERLAND
 Bibliotheek, Inst. Voor Plasma-Fysica, THE NETHERLANDS
 Asst. Prof. Dr. S. Cakir, Middle East Tech. Univ., TURKEY
 Dr. V.A. Glukhikh, Sci. Res. Inst. Electrophys. Apparatus, USSR
 Dr. D.D. Ryutov, Siberian Branch of Academy of Sci., USSR
 Dr. G.A. Eliseev, I.V. Kurchatov Inst., USSR
 Librarian, The Ukr.SSR Academy of Sciences, USSR
 Dr. L.M. Kovrizhnykh, Inst. of General Physics, USSR
 Kernforschungsanlage GmbH, Zentralbibliothek, W. GERMANY
 Bibliothek, Inst. Für Plasmaforschung, W. GERMANY
 Prof. K. Schindler, Ruhr-Universität Bochum, W. GERMANY
 Dr. F. Wagner, (ASDEX), Max-Planck-Institut, W. GERMANY
 Librarian, Max-Planck-Institut, W. GERMANY