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D.L. JASSBY, ET AL.

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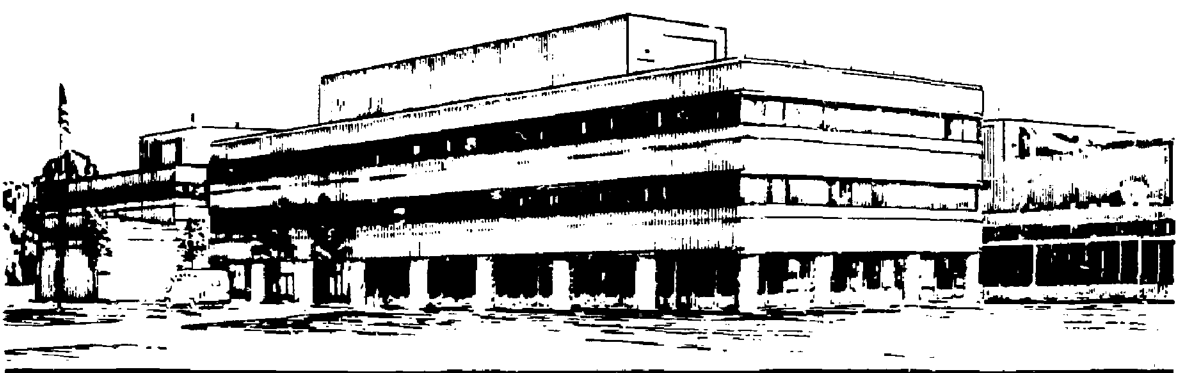

PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY

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HIGH-Q PLASMAS IN THE TFTR TOKAMAK

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D. L. Jassby, C. W. Barnes[a], M. G. Bell, M. Bitter, R. Boivin, N.L. Bretz, R.V. Budny, C.E. Bush[b], H.F. Dylla, P. C. Efthimion, E. D. Fredrickson, R. J. Hawryluk, K.W. Hill, J. Hosea, H. Hsuan, A. C. Janos, F. C. Jobes, D. W. Johnson, L. C. Johnson, J. Kamperschroer, C. Kieras-Phillips, S. J. Kilpatrick, P. H. LaMarche, B. LeBlanc, D.K. Mansfield, E.S. Marmar[c], D.C. McCune, K.M. McGuire, D.M. Meade, S.S. Medley, D. R. Mikkelsen, D. Mueller, D. K. Owens, H. K. Park, S. F. Paul, S. Pitcher, A. T. Ramsey, M. H. Redi, S. A. Sabbagh[d], S. D. Scott, J. Snipes[c], J. Stevens, J. D. Strachan, B. C. Stratton, E. J. Synakowski, G. Taylor, J. L. Terry[c], J. R. Timberlake, H. H. Towner, M. Ulrickson, S. von Goeler, R. M. Wieland, M. Williams, J. R. Wilson, K.-L. Wong, K. M. Young, M. C. Zarnstorff, and S. J. Zweben

Plasma Physics Laboratory, Princeton University
Princeton, New Jersey 08543

[a]Los Alamos National Laboratory, Los Alamos, NM
[b]Oak Ridge National Laboratory, Oak Ridge, TN
[c]Massachusetts Institute of Technology, Cambridge, MA
[d]Columbia University, New York, NY

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ABSTRACT

In the Tokamak Fusion Test Reactor (TFTR) [Plasma Physics and Controlled Fusion 26, 11 (1984)], the highest neutron source strength S_n and D-D fusion power gain Q_{DD} are realized in the neutral-beam fueled and heated "supershot" regime that occurs after extensive wall conditioning to minimize recycling. For the best supershots, S_n increases approximately as $P_b^{1.8}$. The highest-Q shots are characterized by high T_e (up to 12 keV), T_i (up to 34 keV) and stored energy (up to 4.7 MJ), highly peaked density profiles, broad T_e profiles, and lower Z_{eff}. Replacement of critical areas of the graphite limiter tiles with carbon-fiber composite tiles, and improved alignment with the plasma, have mitigated the "carbon bloom." Wall conditioning by lithium pellet injection prior to the beam pulse reduces carbon influx and particle recycling. Empirically, Q_{DD} increases with decreasing pre-injection carbon radiation, and increases strongly with density peakedness ($n_e(0)/\langle n_e \rangle$) during the beam pulse. To date the best fusion results are $S_n = 5 \times 10^{16}$ n/s, $Q_{DD} = 1.85 \times 10^{-3}$, and neutron yield = 4.0×10^{16} n/pulse, obtained at I_p = 1.6 to 1.9 MA and beam energy E_b = 95 to 103 keV, with nearly balanced co- and counter-injected beam power. Computer simulations of supershot plasmas show that typically 50-60% of S_n arises from beam-target reactions, with the remainder divided between beam-beam and thermonuclear reactions, the thermonuclear fraction increasing with P_b. The simulations predict that Q_{DT} = 0.3 to 0.4 would be obtained for the best present plasma conditions, if half the deuterium neutral beams were to be replaced by tritium beams. Somewhat higher values are calculated if D beams are injected into a predominantly tritium target plasma. The projected central beta of fusion alphas is 0.4-0.6%, a level sufficent for the study of alpha-induced collective effects.

I. INTRODUCTION

The TFTR (Tokamak Fusion Test Reactor)[1] is a large tokamak with a vessel major radius of 2.65 m, a magnetic field up to 4.8 T at this position, and a plasma current up to 3 MA. Four neutral-beam injectors deliver up to 33 MW with accelerating beam voltage up to 110 keV, with a pulse length up to 2 s. RF heating power up to 6.3 MW in the ion cyclotron frequency range is also available. The maximum pulse repetition rate at full machine parameters is once every 7.5 min. The tokamak is equipped with diagnostics that measure the radial profiles of important plasma parameters on a single shot.[1]

The main objective of the TFTR effort is to create the plasma conditions for entry into the DT-burning alpha-physics regime. Consequently, maximization of both the fusion reaction rate and the alpha pressure are major goals of the TFTR program. We have been working toward these goals by optimizing the fusion performance of deuterium plasmas. The most important fusion parameters are neutron emission rate, S_n (neutrons/sec), and fusion power gain, $Q_{DD} = S_n x(7.25\ \mathrm{MeV})/P_{heat}$, where the plasma heating power P_{heat} is the sum of the injected neutral-beam and RF powers. (Ohmic power is negligible.)

Figure 1 shows the D-D neutron emission rate as a function of heating power for the principal TFTR operating regimes. S_n varies from the 10^{14} n/s range with RF heating and pellet injection, to the 10^{15} n/s range in the "L-mode" with neutral beams, up to about 10^{16} n/s in a beam-heated regime with $T_i \geq T_e$ that occasionally uses pellets. The range extending beyond 10^{16} n/s can be reached only in the beam-fueled "supershot" regime.[2]

This paper summarizes characteristics of the supershot regime, and discuss recent enhancement of supershot performance. We then project the parameters achieved in D plasmas to D-T operation, and show that experiments on alpha-driven collective effects are possible with Q_{DT} in the range 0.3 to 0.5.

II. NEUTRON DETECTOR SYSTEM

The neutron rate in TFTR is measured principally with a system of fission chambers that cover the range from 10^{10} n/s in ohmic D plasmas to 10^{19} n/s expected in beam-injected D-T plasmas.

Maintaining the neutron detector calibration is an ongoing routine operation.[3] Every 12 to 18 months, we perform an *in situ* absolute calibration of the most sensitive detectors using a Cf-252 source or D-D generator at many positions inside the vacuum vessel, to simulate the plasma source. About once per month we monitor the detector drift, if any, with a Pu-Be or Cf-252 source placed adjacent to the detector. On each day of plasma operation, we cross-calibrate the detectors against each other, using the plasma neutron source.

The absolute uncertainty in the quoted neutron rate for a single shot is ±14%. The injected beam power is known to ±13%, so that the uncertainty in Q_{DD} is about ±19%.

III. DISTINCTIVE FEATURES OF SUPERSHOT PLASMAS

The basic technique for achieving supershots is to inject high-power neutral beams into a low-density target plasma with a graphite first wall/limiter that has been conditioned to achieve a low recycling coefficient R_{cy} for hydrogenic species.[2,4] A second requirement is that central fueling and most heating be provided by neutral-beam injection alone. Other requirements are that the beam power density be high (central value ≥ 1 MW/m^3), and that the beams be injected with roughly balanced co- and counter-injected power (with respect to the plasma current).

Conditioning during the run is carried out principally by ohmic discharges in helium, low-current disruptive discharges, and repetitive high-power neutral-beam injection.[4] After the limiter has been conditioned, the target plasmas are predominantly carbon, and impurity generation appears to control the minimum target density attainable. With a well-conditioned limiter, during beam injection the recycling rate of deuterium from the limiter is small ($R_{cy} \approx 0.5$), and the carbon influx to the plasma is relatively low.

Distinctive features of the supershot,[2,5] compared with other operating modes, include a highly peaked density profile, a broad electron temperature profile, and a very high central ion temperature $T_i(0)$ that is several times higher than $T_e(0)$. While the *pre-injection* density must be low, the central density in a supershot is quite high, up to $10^{20}/m^3$, and the central pressure is as large as 6.5 atmospheres.

The supershot plasma features enhanced confinement relative to standard predictions for beam-heated tokamak plasmas, and exhibits different scaling[5]— the energy confinement time τ_E is essentially independent of beam power P_b and plasma current I_p, until the β limit is encountered for a given I_p. (Typically, τ_E is 2 to 3 times the L-mode value.) The current is predominantly beam-driven and bootstrap, as suggested by the negative surface voltage and confirmed by theoretical analysis.[6] Sawteeth are stabilized in the supershot regime, possibly because of current profile modification by the non-inductive currents. Table I summarizes the plasma parameters achieved to date in supershots.

IV. NEUTRON PRODUCTION IN SUPERSHOTS

As indicated in Fig. 2, the neutron rate in a supershot becomes very large after 300-400 ms of beam injection, as T_i, T_e and $n_e(0)$ reach high levels. There are 3 sources of fusion neutrons in beam-injected plasmas, namely thermal, beam-thermal, and beam-beam reactions. The *TRANSP* code[7] is used to calculate the time dependence of each of these sources. The total reaction rate calculated by TRANSP, using the measured temperature and density profiles, is generally in good agreement (±15%) with the measured neutron rate. In high-powered supershots, such as illustrated in Fig. 2, beam-thermal reactions typically account for about one-half the total neutron rate, thermal reactions for one-third, and beam-beam reactions for one-sixth. Because of their high reactivity, the beam-thermal and beam-beam components allow a high fusion rate with fewer particles to thermalize charged fusion products, so that in D-T operation higher alpha pressure will be realized.

Figure 3 shows S_n versus P_b for about 800 supershots. Here S_n is the maximum value during the pulse. For the best supershots, S_n increases approximately as $P_b^{1.8}$. At a given P_b, higher S_n is generally correlated with higher density peakedness, lower Z_{eff}, reduced MHD activity, and higher T_e. The $P_b^{1.8}$ dependence of S_n for the best supershots is a consequence of the 3 sources of fusion reactions, the central plasma fueling by neutral beam injection, and τ_E being essentially independent of P_b. The plasma density and temperature increase with increasing P_b, leading to the thermal reaction rate rising much faster than P_b^2, the beam-thermal rate somewhat more slowly than P_b^2, and the beam-beam rate considerably more slowly than P_b^2.

V. RECENT PROGRESS IN SUPERSHOTS

In Fig. 3, the 1990 data are differentiated from data obtained in previous years, mainly 1988 and 1989. Evidently, the 1990 run featured consistent operation at the highest beam power available, and generally improved performance at lower beam powers. The following are the areas in which substantial improvements have been made in 1990.

a) *Limiter Tiles.* Previously, the "carbon bloom", or runaway sublimation of carbon from the limiter, reduced fusion performance at high beam power.[4] Before the 1990 run, critical areas of the poco-graphite limiter tiles were replaced with carbon fiber composite tiles, and their alignment with the plasma was improved so that the limiter could better absorb the escaping heat and particle fluxes.[8] These changes served to eliminate or at least postpone the bloom to a later time in the pulse and greatly diminish its intensity.

b) *Lithium Pellets.* Shots with the highest neutron emission at high P_b, and many of the best shots at moderate P_b, made use of pre-beam lithium pellet injection.[9] Figure 4 shows S_n versus P_b with and without pre-beam Li injection for shots on a single run day. As indicated by the inset diagram, the small Li pellet is optimally injected about 1 sec before beams are turned on, so that the Li can diffuse out and cover the limiter, the plasma density returning to its initial level. The shots with Li pellets have S_n up to 20% higher than the no-pellet shots. Lower carbon light emission and lower Z_{eff} suggest that wall conditioning by pre-beam lithium pellet injection reduces carbon influx.

c) *Controlled Carbon Blooms.* While the naturally occuring bloom has practically been eliminated, an effective means of reducing the low-level carbon influx is to generate intentionally a carbon bloom by moving the plasma to a new portion of the limiter. This technique often results in greatly reduced carbon influx during subsequent shots.

d) *Current Up-Ramping.* Using large I_p before the beam pulse appears to aggravate particle recycling from the limiter. But with increasing beam power, it is important to be able to extend supershot operation to higher I_p in order to avoid β limitations. This objective was achieved by ramping of I_p during the beam pulse, e.g. from 1.4 to 1.6 MA or from 1.6 to 1.9 MA, enabling some of the best supershots to be produced at I_p up to 1.9 MA. There was found to be no I_p dependence of τ_E

during the current up-ramp. While the change in I_p was only 15-20%, in general τ_E in supershots does not depend on I_p, as hoted previously.

With the above improvements, stable operation of supershots has been achieved with P_b up to 33 MW and stored energy up to 4.7 MJ. However, magnetohydrodynamic stability remains a serious limitation to supershot performance. In the extreme case, at lower I_p and higher P_b, there can be major disruptions at the beta limit. More frequently, the onset of global resistive-type modes, typically of low m-number, m/n = 1/1, 2/1, 3/2 and 4/3, causes confinement degradation.

Figure 5 examines some features of the shot with highest neutron rate and stored energy to date (#55806). This shot appeared to evolve to a new equilibrium level at 0.45 s into the beam pulse (t = 3.45 s). At this time, $T_e(0)$ and S_n dropped abruptly and $n_e(r)$ broadened. The drop in S_n coincided with a sharp increase in coherent MHD activity. The detected flux of 1-MeV D-D tritons on loss orbits increased gradually with S_n until t = 3.45 s, as expected, but then jumped upward simultaneously with the increase in MHD activity.

Other supershot investigations, of potential importance for future performance enhancement, include the following:

a) *Ion cyclotron resonant heating* has been found to be effective in stabilizing sawteeth and increasing T_e during supershots.[10] This technique may prove important for extending the supershot operating regime to $I_p \geq 2$ MA.

b) *Plasma Press.* Size variation experiments had suggested that S_n could be increased in smaller-volume plasmas if τ_E could be maintained. One way to decrease volume is by compression. In the present machine configuration, adiabatic compression is not possible, but the plasma can be pressed slowly against the inner (bumper) limiter, reducing both R and a. It was found that τ_E remained essentially constant with a slow (~100 ms) reduction in R through a modest 15 cm, although the plasma was terminated soon after. In the best case, this technique gave a 23% increase in $n_e(0)$, a 14% increase in $T_e(0)$, and a 17% increase in S_n at the end of the pressing action. The TRANSP code analysis showed that the thermal reaction rate rose nearly 50% because of the substantial density increase, to about 3/4 of the beam-thermal reaction rate.

c) *Overdrive.* Injection of a short (~0.1 s) beam pulse at an unusually high power level for a given I_p ("overdriving"), then reducing P_b to a level compatible with β limits, gave substantially higher density peakedness, stored energy, and neutron emission rate than the usual values at the lower P_b. To date this technique has given favorable results only at low I_p.

d) *High β_p.* Operation at very high β_p has been made possible by means of current rampdown prior to beam injection, which appears to modify the current profile. With this technique, the stored energy at a given q_a can be doubled.[11] This regime appears to be a type of supershot featuring a much higher β limit than usual, and merits further exploration.

VI. PROJECTIONS TO D-T OPERATION

The calculation of fusion performance to be expected with a beam-driven D-T plasma is not simple because of uncertainties in profiles, fast-ion velocity distributions, impurity levels, and energy confinement. The quoted D-D Q-values are based on direct measurement of fusion neutrons. The *TRANSP* and *SNAP* computer simulations predict neutron rates in good agreement (generally ±15%) with the measured values, when the experimental plasma profiles are input to the codes. Thus we are confident in using *TRANSP* and *SNAP* to determine the ratio of the D-T reaction rate to the D-D reaction rate for a given TFTR shot, assuming the *same* beam parameters, plasma parameters, profiles, and impurity content measured in the actual deuterium shot.

We have considered two modes of D-T operation:

1) In Mode A, half the D neutral beams are replaced with T beams of the same energy, to maintain a 50-50 isotopic mix in the (beam-fueled) plasma. The plasma profiles and Z_{eff} are kept the same as measured in deuterium operation. The calculated D-D to D-T conversion factor is 70 - 80 for S_n and 175 - 200 for Q.

2) In Mode B, the supershot is first established with 100% T beams. Then the beam source gas is switched to D, so that 100% D beams are injected into the predominantly tritium thermal plasma. Again, the plasma profiles and Z_{eff} are the same as actually measured in deuterium operation. The calculated D-D to D-T conversion factor is 90 - 105 for S_n and 220 - 240 for Q.

Mode B gives a somewhat larger Q_{DT} than Mode A for the same plasma conditions, but is only transient, the high fusion output lasting about one beam-ion slowing-down time (~0.1 s). This period could be lengthened by slow compression in major radius.

Figure 6 shows the measured Q_{DD} versus beam power for the same set of 800 supershots as before. (In calculating Q_{DD}, P_{inj} is the total injected beam power, regardless of how much is absorbed.) While each shot has a unique Q_{DD}, the calculated equivalent Q_{DT} lies in the range of 180 to 240 x Q_{DD}, the exact value depending on the operational mode and the specific plasma parameters for that shot This range is reflected on the right-hand scale in Fig. 6. There are numerous shots with equivalent Q_{DT} between 0.3 and 0.4.

Figure 7 shows a TRANSP code simulation of D-T fusion power versus time for a specific shot, in which the thermal reaction rate became nearly equal to the beam-thermal rate. This shot had a small compression of 15 cm in R between 3.6 and 3.75 s, but we will consider the fusion output just before compression. For the 50-50

D-T case (Mode A), using the same beam and plasma parameters of the actual deuterium shot, the maximum Q_{DT} is calculated to be 0.31, and the central β_α is 0.4%. For the $D^o \to T^+$ case (Mode B), the beam-thermal fusion rate is twice the thermal rate, but Q_{DT} increases to about 0.36. and the central β_α is 0.5%. If we arbitrarily decrease Z_{eff} from 2.4 to 1.5, and increase the beam energy from 103 keV to 115 keV, Q_{DT} for Mode B increases to about 0.5 and the central β_α to 1.1%.

VII. CONFINEMENT AND BURNUP OF D-D TRITONS

One of the principal objectives of D-T operation in TFTR is to explore alpha-particle physics. Meanwhile experiments with MeV fusion products are being done now using the 1-MeV D-D tritons from the second D-D fusion reaction. (The two D-D reactions have nearly equal cross sections.) Both escaping tritons and 14-MeV neutrons from the burnup of confined tritons are measured.

Energetic tritons lost from the plasma are monitored with detectors located near the vessel wall.[12] The measured loss rate (normalized to S_n) decreases with rising I_p in agreement with the calculated first-orbit loss, when MHD activity is low. These measurements show that triton loss is small at $I_p > 1.5$ MA, except during strong MHD activity, or when the major radius is increased so that TF ripple losses are significant.

Activation foil measurements show that the ratio of D-T to D-D neutrons per pulse is in the range 0.3 to 1%, which is 1/2 to 1 times the calculated values assuming first-orbit losses only and classical slowing-down.[13] Hence at least 1/2 of the tritons are confined until they thermalize.

Figure 8 shows the measurement of the time dependence of the 14-MeV neutron emission using helium proportional counters in the TFTR multi-channel collimator.[14] The 14-MeV neutron emission has a markedly different time dependence than the D-D emission. After the neutral beams are turned off, the neutron source becomes predominantly 14-MeV, because the 1-MeV tritons have a much longer slowing-down time than the beam-injected deuterons.

The 3.5-MeV D-T alphas have approximately the same gyroradius as 1-MeV tritons, while the triton slowing-down time is several times longer. Hence most alphas should be confined and thermalize classically in D-T TFTR plasmas with $I_p >$ 1.5 MA, in the absence of intense MHD activity.

Now we will consider whether the expected good alpha confinement may be lost due to alpha-induced collective effects. Table II shows theoretical estimates of the thresholds for fusion-alpha collective effects in TFTR.[15] As indicated previously, the present TFTR plasma parameters will give core β_α = 0.4-0.6% in D-T operation, which is large enough to excite most of these instabilities. Thus alpha collective effects should be observable in D-T experiments.

Toroidal Alfven Eigenmodes (TAE modes) driven by neutral-beam-injected ions have been observed on TFTR operating at reduced parameters of $B_t \sim 1.0$ T and $I_p \sim$ 500 kA. Injection of 14 MW of 100-keV neutral beams produced $\beta_{beam} \sim 0.5\%$. Density and magnetic fluctuations were observed in the range of 70 to 140 kHz, in reasonable agreement with calculated TAE values.[16] The neutron rate dropped, suggesting expulsion of beam ions (and a possible problem for alpha confinement in D-T plasmas.)

VIII. SUMMARY OF TFTR FUSION PERFORMANCE

Table III summarizes the fusion performance of TFTR. Supershot discharges have produced reactor-level plasma parameters of $T_i(0)$ up to 34 keV, $T_e(0)$ up to 12 keV, and $n_e(0)$ up to 1×10^{20} m^{-3}, with fusion reactions in deuterium producing up to 5×10^{16} neutrons/sec and $Q_{DD} = 1.85\times10^{-3}$. These *presently achieved* plasma parameters will, in D-T operation, give 14-MeV neutron and 3.5-MeV alpha production rates of 3 to 5×10^{18}/sec (9 to 13 MW fusion power) at $Q_{DT} \sim 0.3$ to 0.4, depending on operational mode.

The 1-MeV D-D tritons simulate alpha dynamics, and experimentally appear to be well confined at higher TFTR currents (in the absence of strong MHD activity). For the best shots, $\beta_\alpha(0)$ up to 0.6% is expected with present plasma parameters in D-T, with the ratio of alpha velocity to Alfven velocity being 1.5 - 2. These levels are sufficient to allow the study of alpha-particle collective effects, including the thresholds of possible alpha-induced instabilities. Thus the two-energy component (beam-dominated) approach lends itself well to producing high fusion rates and reactor level β_α in tokamaks with $Q \leq 1$.

Control of first-wall conditions continues to be the dominant factor in the performance of supershots, although performance of the best shots is now mostly limited by MHD stability. A multiple-pellet lithium injection capability is being installed to improve wall conditioning. Larger values of Q_{DT} and β_α are projected with higher beam power and beam voltage, especially if the central density can be increased and Z_{eff} reduced from present levels near 2.5, and if τ_E is increased in D-T plasmas above the values found in deuterium.

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TABLE I

SUPERSHOT PARAMETER RANGE

I_p	0.8 - 1.9 MA
$T_i(0)$	20 - 34 keV
$T_e(0)$	7 - 12 keV
$n_e(0)$	(0.5 - 1) x 10^{20} m^{-3}
τ_E	120 - 175 ms
Z_{eff}	2.2 - 4
Plasma energy	≤ 4.7 MJ
Central pressure	≤ 6.5 atm

TABLE II

THEORETICAL ESTIMATES OF THRESHOLDS FOR ALPHA COLLECTIVE EFFECTS

INSTABILITY	Approx. Threshold β_α (near q ~ 1 radius)
Fishbones	~ 1%
Sawtooth Stabilization	~0.5%.
Toroidal Alfven Eigenmodes (TAE)	~0.3%, and $V_\alpha \sim V_{Alf}$
High-n Ballooning	~0.1%

Presently achieved TFTR plasma parameters in deuterium would give $\beta_\alpha(0) = 0.4\text{-}0.6\%$ in D-T operation.

TABLE III

SUMMARY OF TFTR FUSION PERFORMANCE

ACTUAL PERFORMANCE IN DEUTERIUM

Max. D-D Neutron Rate	5.0×10^{16} n/sec	(58 kW)
Max. Q_{DD}	1.85×10^{-3}	
Max. D-D Neutrons/Pulse	4.0×10^{16}	(46 kJ energy)

EQUIVALENT PERFORMANCE IN D-T

Using measured plasma profiles and composition, and present beam parameters

Q_{DT}	0.3 - 0.4
Fusion Power Output	9 - 13 MW
Fusion Power Density (at plasma center)	1.8 - 2.4 MW/m^3

ALPHA PHYSICS PARAMETERS

PARAMETER	TFTR, EQUIV. D-T	FULL-SCALE REACTOR
$\beta_\alpha(0)$	0.4 - 0.6%	2.3%
V_α/V_{Alfven}	1.5 - 2.0	2.8

PPPL#90X0569

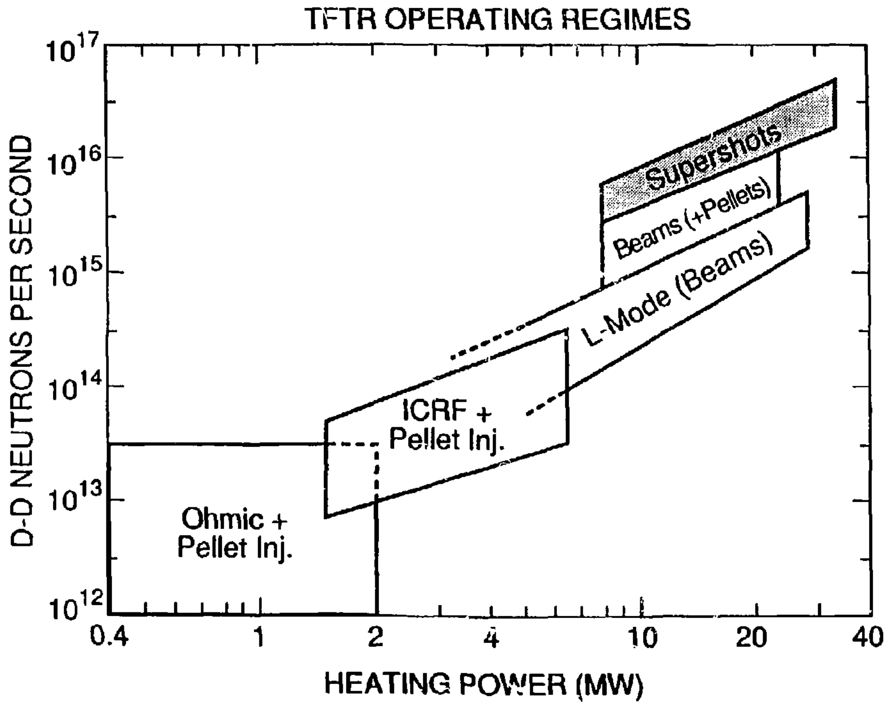


FIG. 1. Measured neutron emission rates in TFTR operating regimes.

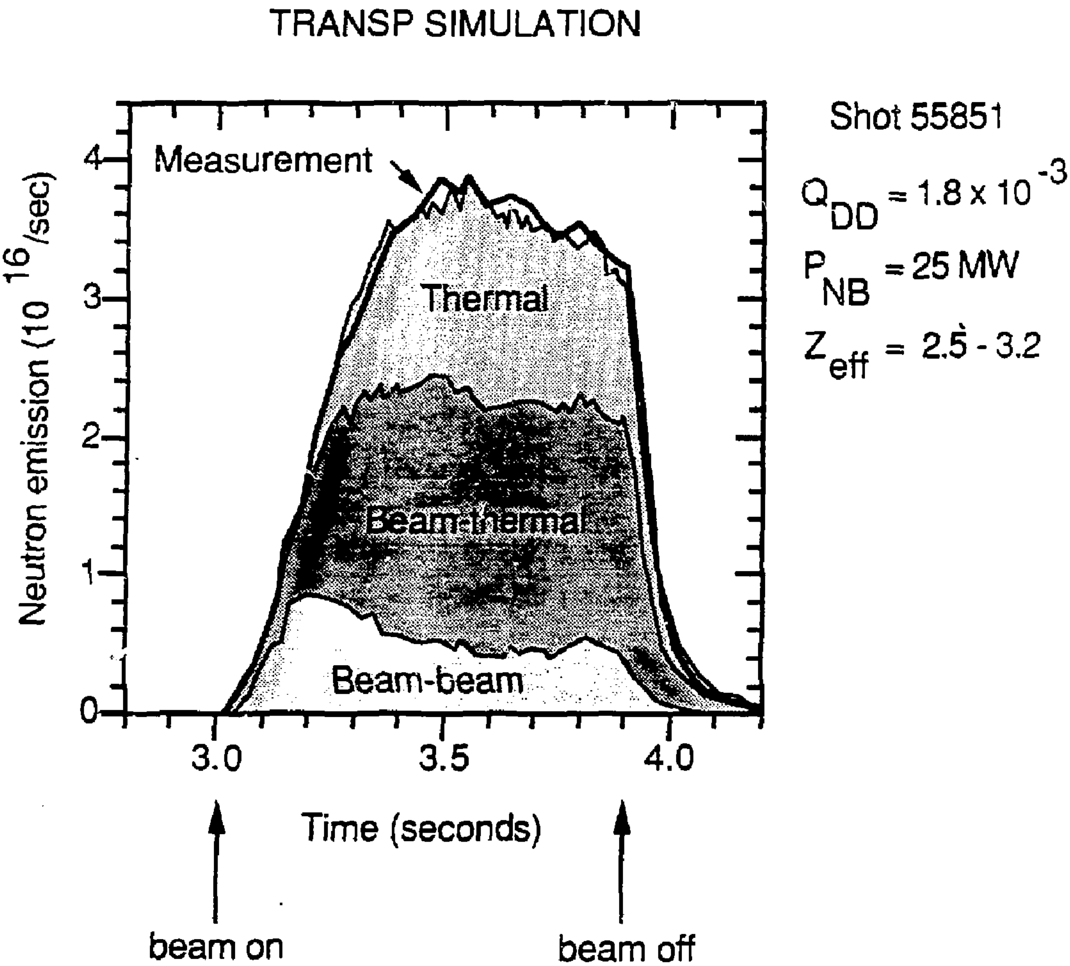


FIG. 2. TRANSP simulation showing the time dependence of the 3 sources of fusion reactions in a TFTR supershot.

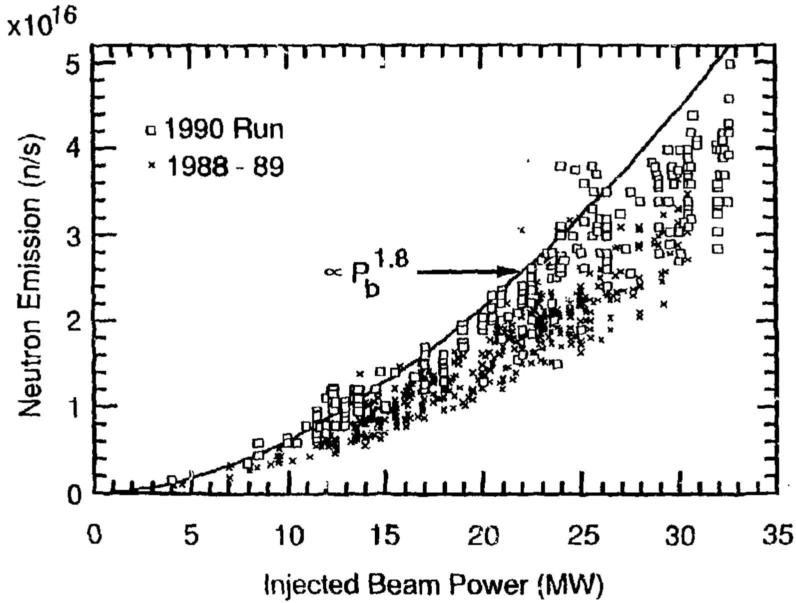


FIG. 3. Neutron emission rate *vs* injected neutral-beam power for TFTR supershots. The neutron rate plotted is the maximum attained during the pulse.

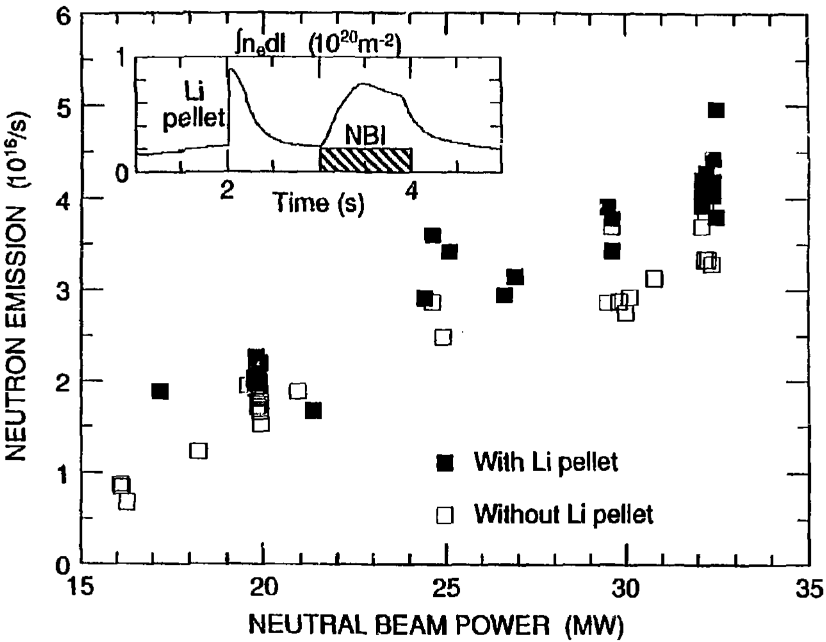


FIG. 4. Maximum neutron emission rates in a series of supershots with and without pre-beam lithium pellet injection. The inset shows the time dependence of line-averaged density for a shot with pellet injection.

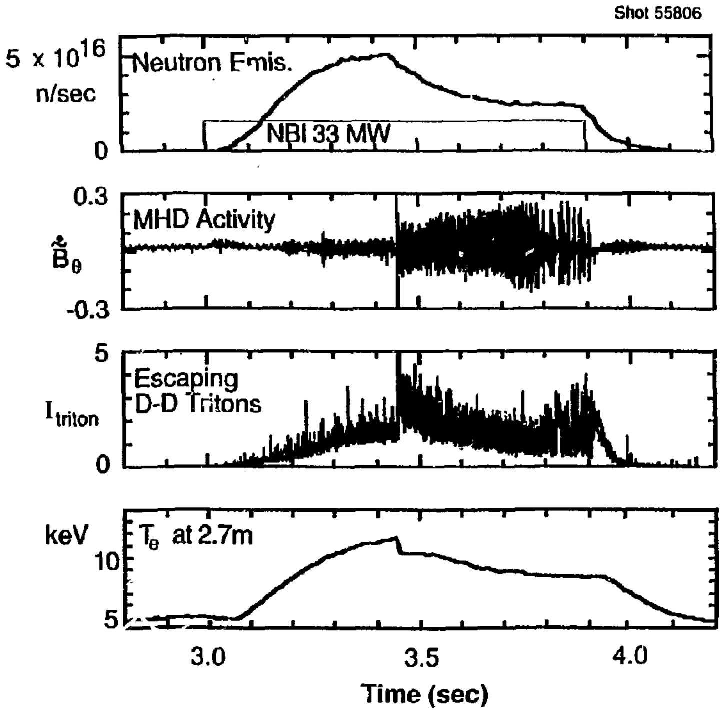
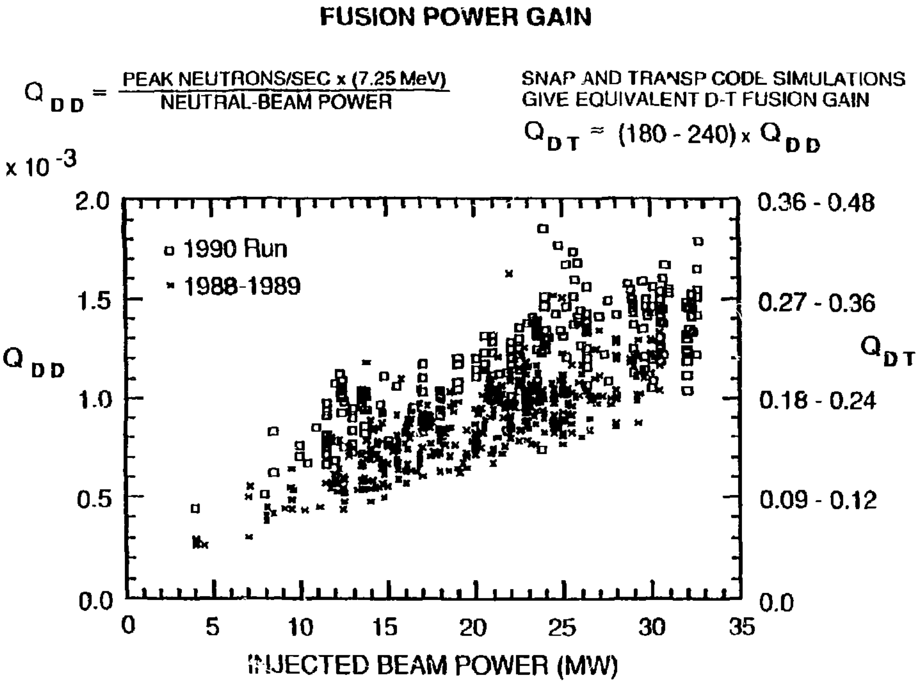


FIG. 5. Time dependence of neutron emission, MHD fluctuation signal, escaping D-D triton flux, and electron temperature, for shot 55806.



<u>FIG. 6</u>. Measured D-D fusion power gain Q_{DD}, and calculated D-T gain Q_{DT}, *vs* injected neutral-beam power for TFTR supershots. SNAP and TRANSP simulations give equivalent D-T fusion gain $Q_{DT} = (180\text{-}240) \times Q_{DD}$.

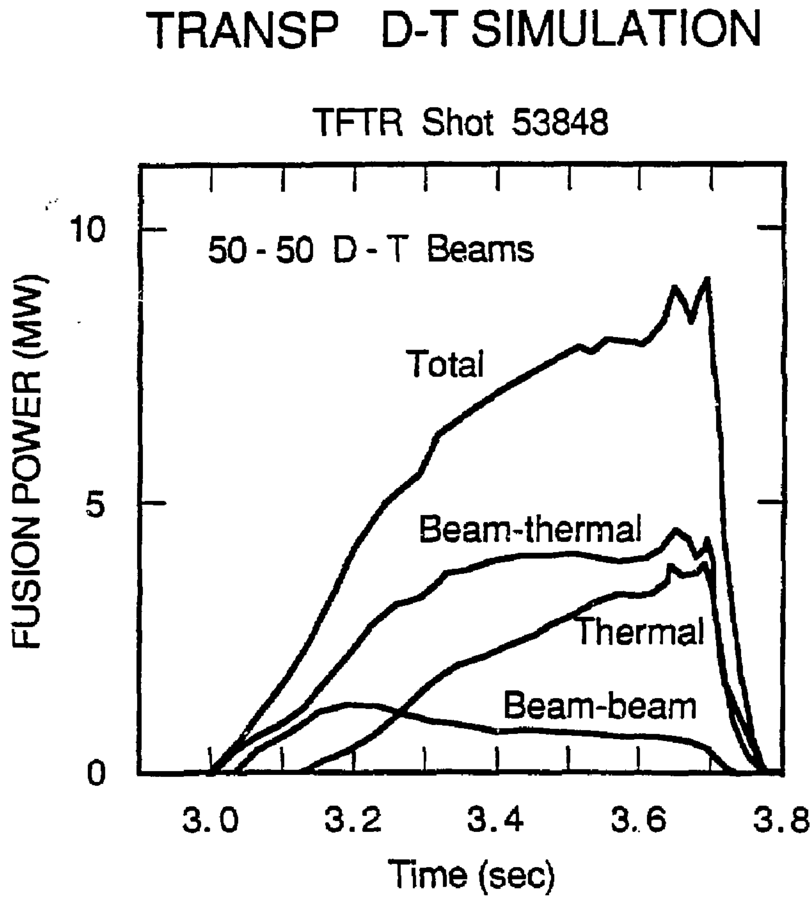


FIG. 7. TRANSP simulation showing the time dependence of the 3 sources of fusion reactions in a TFTR supershot in D-T operation, for the case of equal powers of D and T neutral beams.

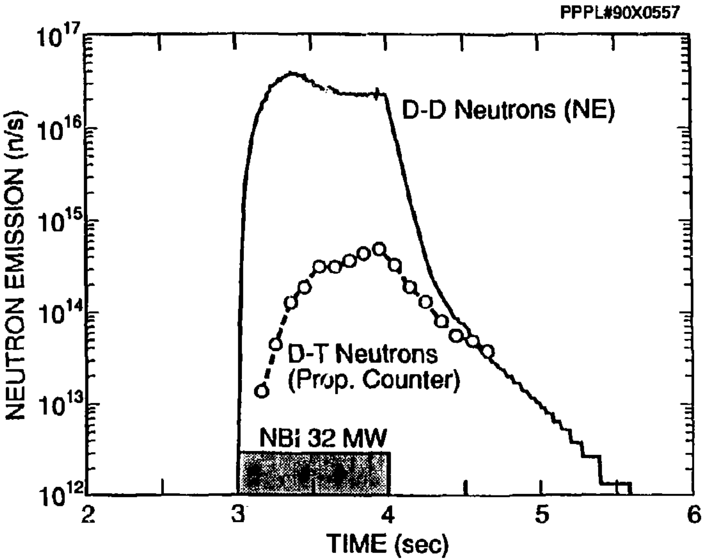


FIG. 8. Measured time dependence of the D-D and D-T neutron emissions, averaged over 10 similar supershots.

FIGURE CAPTIONS

FIG. 1. Measured neutron emission rates in TFTR operating regimes.

FIG. 2. TRANSP simulation showing the time dependence of the 3 sources of fusion reactions in a TFTR supershot.

FIG. 3. Neutron emission rate *vs* injected neutral-beam power for TFTR supershots. The neutron rate plotted is the maximum attained during the pulse.

FIG. 4. Maximum neutron emission rates in a series of supershots with and without pre-beam lithium pellet injection. The inset shows the time dependence of line-averaged density for a shot with pellet injection.

FIG. 5. Time dependence of neutron emission, MHD fluctuation signal, escaping D-D triton flux, and electron temperature, for shot 55806.

FIG. 6. Measured D-D fusion power gain Q_{DD}, and calculated D-T gain Q_{DT}, *vs* injected neutral-beam power for TFTR supershots. SNAP and TRANSP simulations give equivalent D-T fusion gain $Q_{DT} = (180\text{-}240) \times Q_{DD}$.

FIG. 7. TRANSP simulation showing the time dependence of the 3 sources of fusion reactions in a TFTR supershot in D-T operation, for the case of equal powers of D and T neutral beams.

FIG. 8. Measured time dependence of the D-D and D-T neutron emissions, averaged over 10 similar supershots.