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CONF-890384--1

ITER DENSITY PROFILE WITH PELLET INJECTION*

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Oak Ridge, Tennessee 37831

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DE89 008730

Particle transport in multi-pellet fueled JET plasmas is being examined to help evaluate density profile behavior in ITER. Preliminary results of the JET analysis were reported at the IAEA Technical Committee Meeting on Pellets in October 1988.[1] In sawtooth free JET discharges, the density profile evolution after injection of pellets can be modeled with the neoclassical Ware pinch and a diffusion coefficient that is small in the plasma core and increases sharply in the vicinity of the $q = 2$ surface. This model is applicable to both ohmic and central ICRF heated discharges. Some of the auxiliary heated plasmas show a more rapid central density decay that appears to be related to MHD activity observed in soft x-ray signals. In these discharges the density profile evolution can be modeled with a temperature dependent diffusion coefficient and the neoclassical Ware pinch. There is a strong correlation between the inferred local particle and heat transport coefficients in all discharges. Plasmas with non-central pellet penetration show no significant density peaking, consistent with the small Ware pinch term. These results appear to conflict with those reported for ASDEX.[2] There it was found that sustained pellet injection during neutral beam and ICRF heating, with pellet penetration of only half the plasma radius, led to markedly peaked electron density profiles as well as high edge recycling, reduced sawtooth activity, central impurity radiation, enhanced density limit, and improved global energy confinement. Thus, the implications of these results for ITER are still highly speculative because of the lack of knowledge about scaling with machine parameters. The JET results suggest that relatively deep fueling may be required to significantly influence the density profile shape, while the ASDEX results imply that partial penetration may be sufficient.

[1] L. R. Baylor, W. A. Houlberg, S. L. Milora, G. L. Schmidt, and members of the JET-U.S. DOE Pellet Collaboration, "Particle Transport Analysis of Pellet Fueled JET Plasmas," to be published in Proc. IAEA Technical Committee Meeting on Pellet Injection and Toroidal Confinement, Gut Ising FRG, October 1988.

[2] V. Mertens, M. Kaufmann, R. Lang, W. Sandmann, K. Büchl, O. Gruber, K. Lackner, J. M. Noterdaeme, ASDEX, NBI, and ICRH Teams, "Improved Plasma Performance by Repetitive Pellet Injection in ASDEX," to be published in Proc. IAEA Technical Committee Meeting on Pellet Injection and Toroidal Confinement, Gut Ising FRG, October 1988.

*Research sponsored by the Office of Fusion Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

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ITER-Physics, ITER-Technology Calculations

Neutral Beam Current Drive

A set of POPCON plots for the ITER-Technology Phase with Goldston confinement scaling and 1.0 MeV deuterium beams is attached. The reference beta limit of 4.7% (Fig. 1) and beta values (Fig. 2) include thermal and beam contributions. A nominal reference operating point in this case would be at $\langle T \rangle = 15\,\mathrm{keV}$ and $\langle n_e \rangle = 0.6 \times 10^{20}\,\mathrm{m}^{-3}$. The fractional contribution to beta from the beam ions is high (Fig. 3) because of the poor confinement (Fig. 4) and high beam power (Fig. 5). The contour where no inductive current is required (Figs. 1 and 6) roughly corresponds to the 4.7% beta limit contour (Fig. 1). About 90% of the current is supplied by the beams (Fig. 7) and 10% by the bootstrap current (Fig. 8). Because of the low temperature operation, the current drive efficiency is only 0.15 – 0.20 A/w (Fig. 9). From the beam power (Fig. 5) and total fusion power (Fig. 10) curves it can be seen that $Q = P_{fus}/P_{beam} \approx 5$ at the nominal operating point. Improved confinement moves the operating to higher temperatures because of reduced beam power and pressure fraction as well as improved current drive efficiency. All of thses factors lead to improved Q values.

The evolution of the temperature, density, pressure, and current profiles are shown in Figs. 11 and 12 for a 60 s inductive rampup to 18 MA followed by 150 s of $E_D^o = 1$ MeV beam heating and current drive. The 90 MW of beams drives 14.7 MA of current with another 2.7 MA from the bootstrap current. The electron density is centrally peaked because of the deuterium from the beams (Fig. 11). Sawtooth activity keeps $q(0) \approx 1$ so the total current on axis is much less than the highly peaked beam driven current profile (Fig. 12). The sharp changes in gradients induced by the sawtooth activity introduces large localized fluctuations in the bootstrap current (Fig. 12).

Ignition

A set of POPCON plots for the ITER-Physics Phase with 22 MA of current are shown in Figs. 13–17, assuming twice Goldston confinement scaling.

An 80 s inductive current startup followed by 20 s of neutral beam heating at 50 MW and the first 100 s of ignited burn is shown in Figs. 18 and 19. At burn, $\langle \beta_t \rangle_{th} \approx 4\%$ and $\langle \beta_t \rangle_{beam} \approx 1\%$ for a total $\langle \beta_t \rangle_{tot} \approx 5\%$. The electron density profile is flat because neutral gas fueling was used. Pellets could be used to increase the density proile peaking.

Volt-Second Consumption

The volt-second consumption for the 18 MA driven case and the 22 MA ignited case are shown in Fig. 20. They consume a total of 203 V-s and 267 V-s respectively at the end of their current ramp phases. At the end of the simulation in the driven case, $I_{beam} = 14.7$ MA and $I_{boot} = 2.7$ MA for a total noninductive current of 17.4 MA. Overdriving the current on axis in the driven case drives sawtooth activity that leads to a net consumption of flux in the flat-top that is much greater than would be expected for the 0.6 MA of inductive current. This effect needs to be examined more closely, but could lead to a net consumption of flux in steady-state even if the non-inductive current source exceeded the desired total current; it says that the current profile should be controlled so that sawtooth activity is not excited.

[1]S. E. Attenberger, W. A. Houlberg, N. A. Uckan, "Transport Analysis of Ignited and Current-Driven ITER Designs," to be published in Proc. 8th Topical Meeting on Technology of Fusion Energy, Salt Lake City, October 1988.

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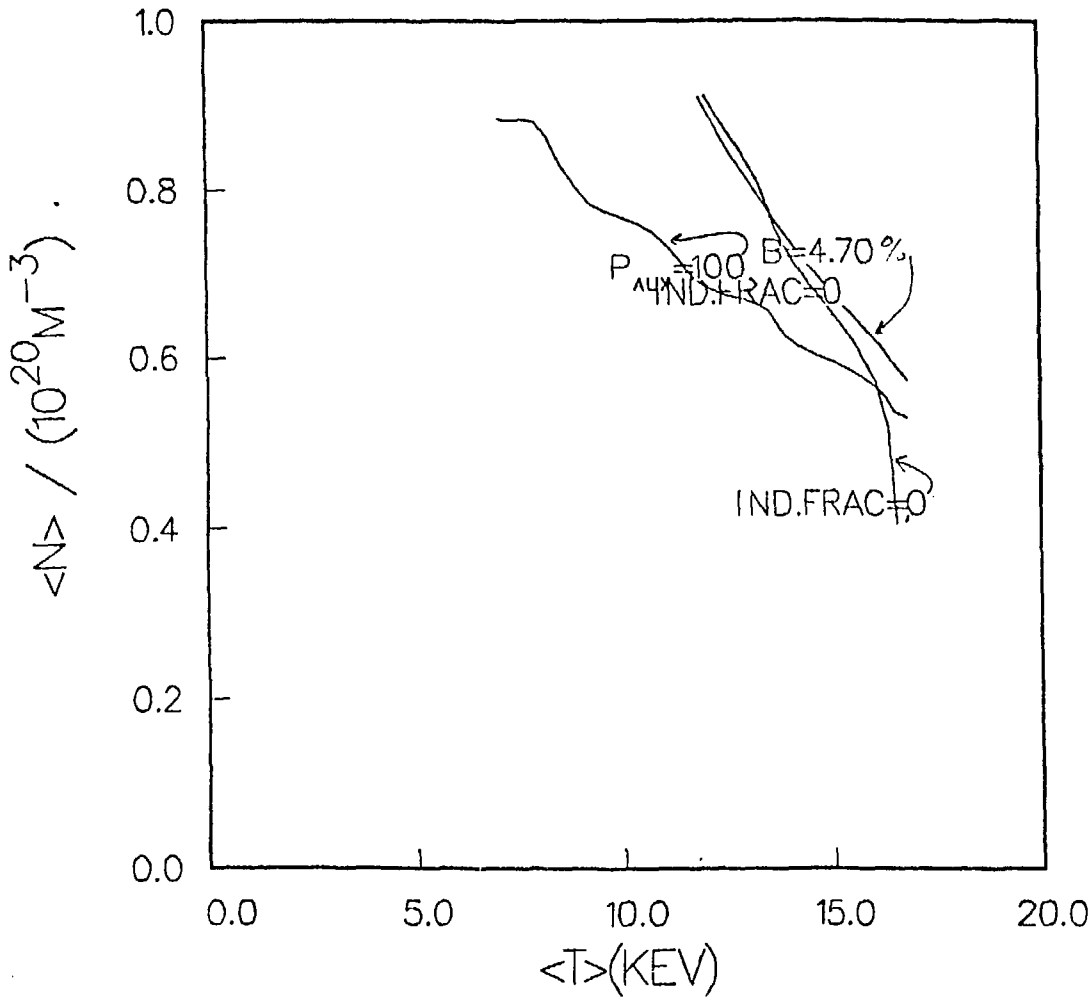
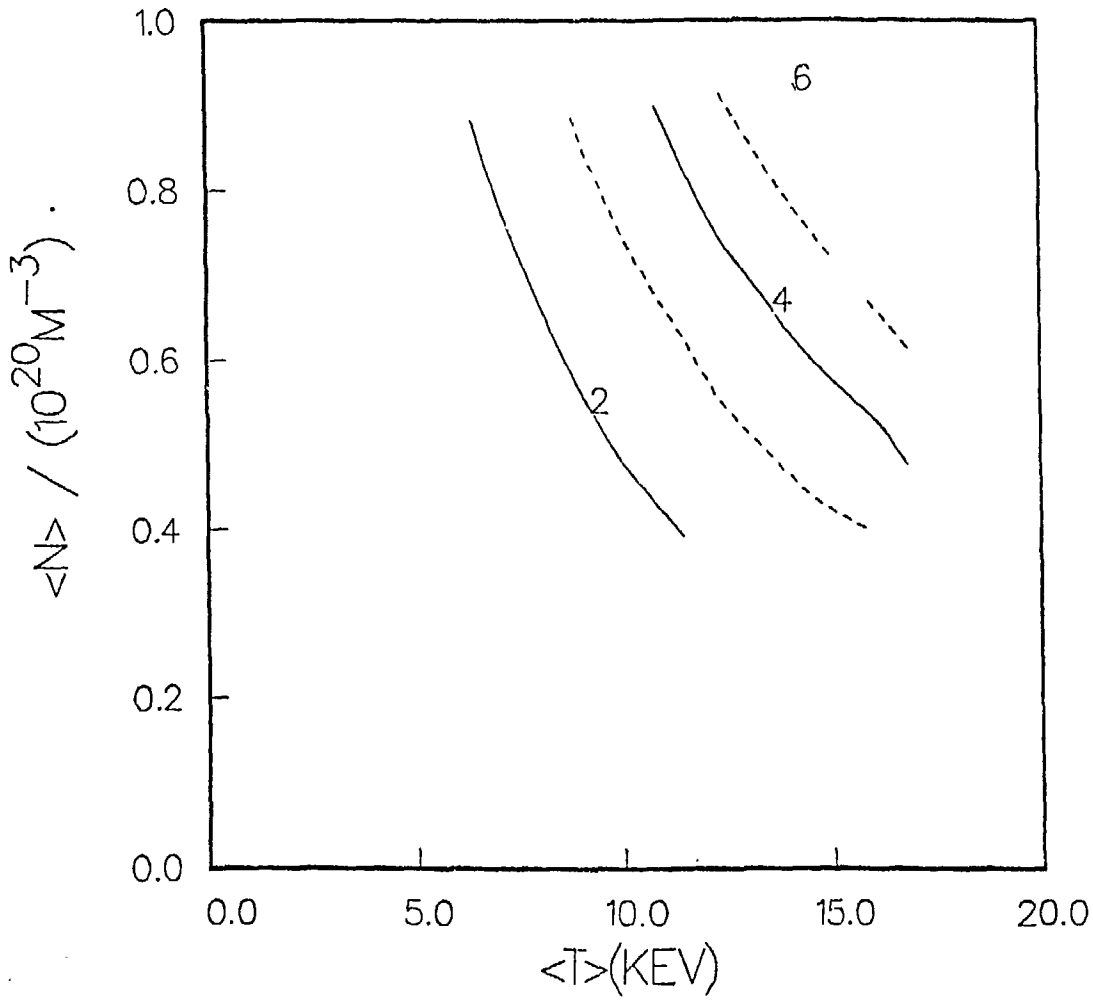
OPERATING REGION



1

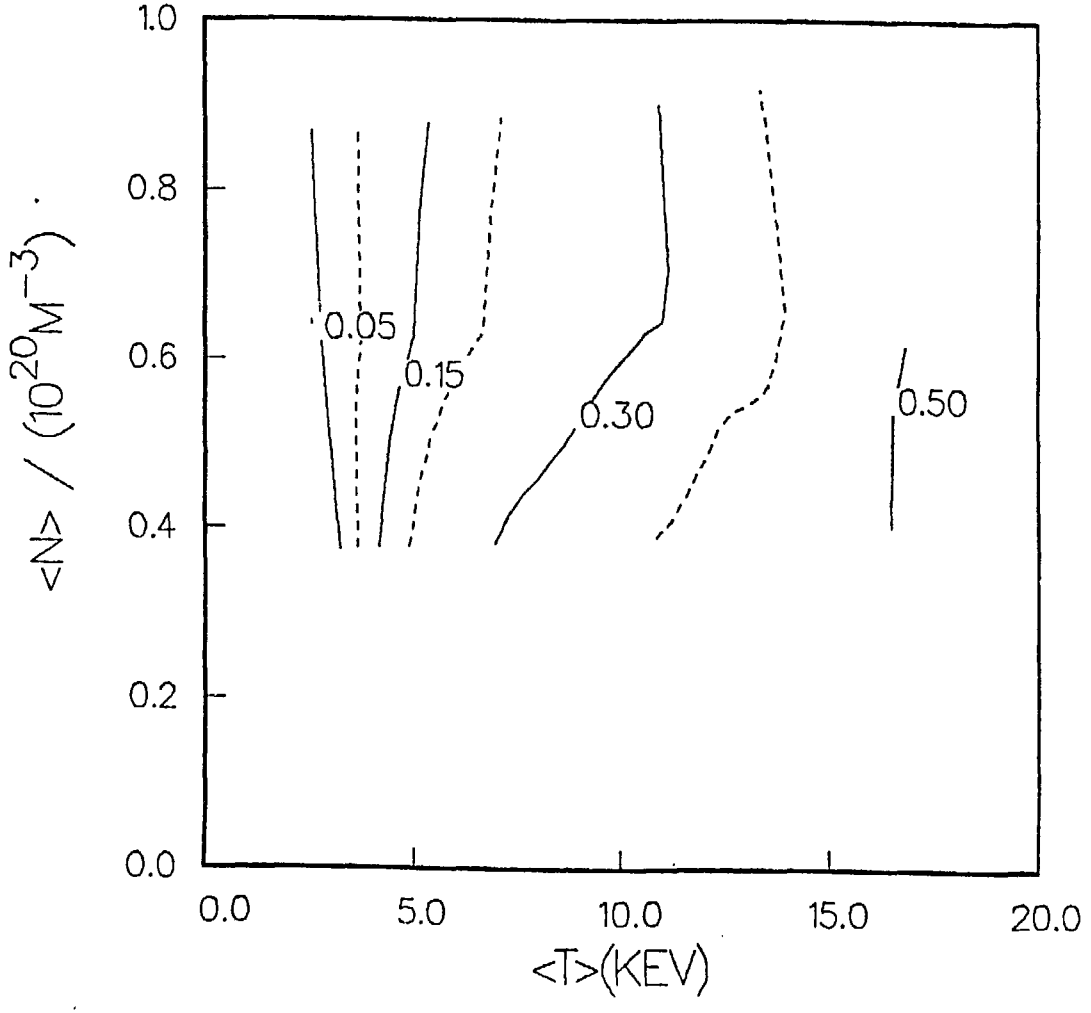
435

TOROIDAL BETA (%)



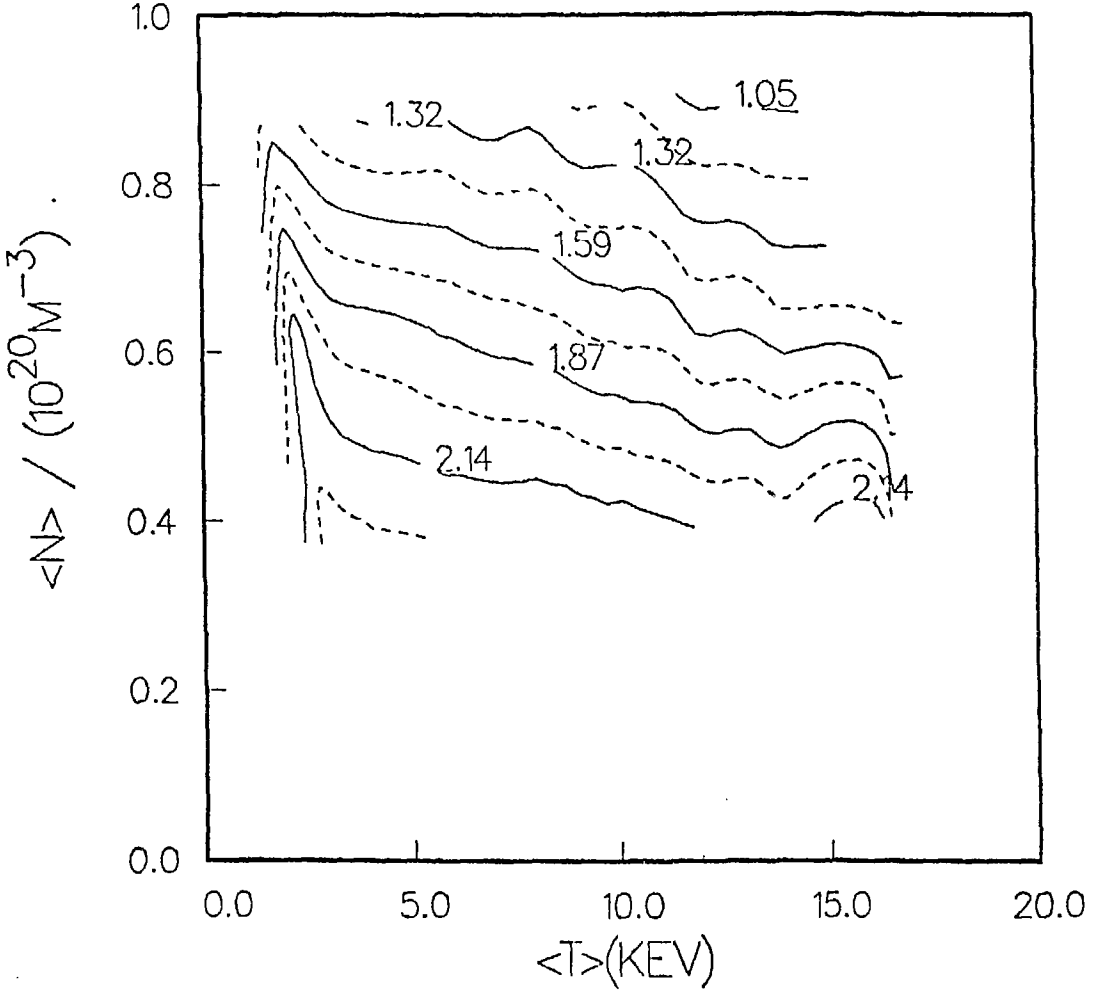
(2)

BEAM PRESSURE FRACTION = PB/(PTOT−PALF−PB)

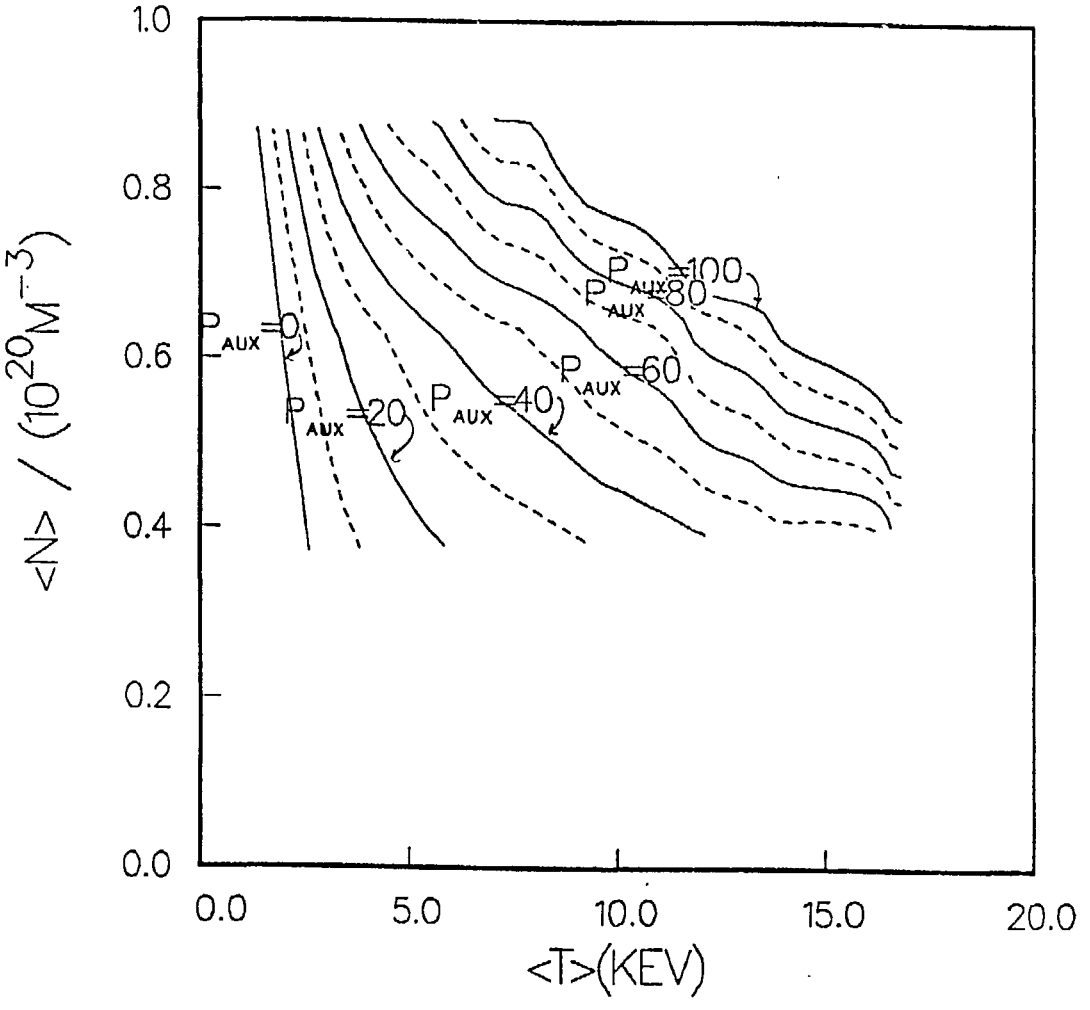


3

ENERGY CONFINEMENT TIME (S)

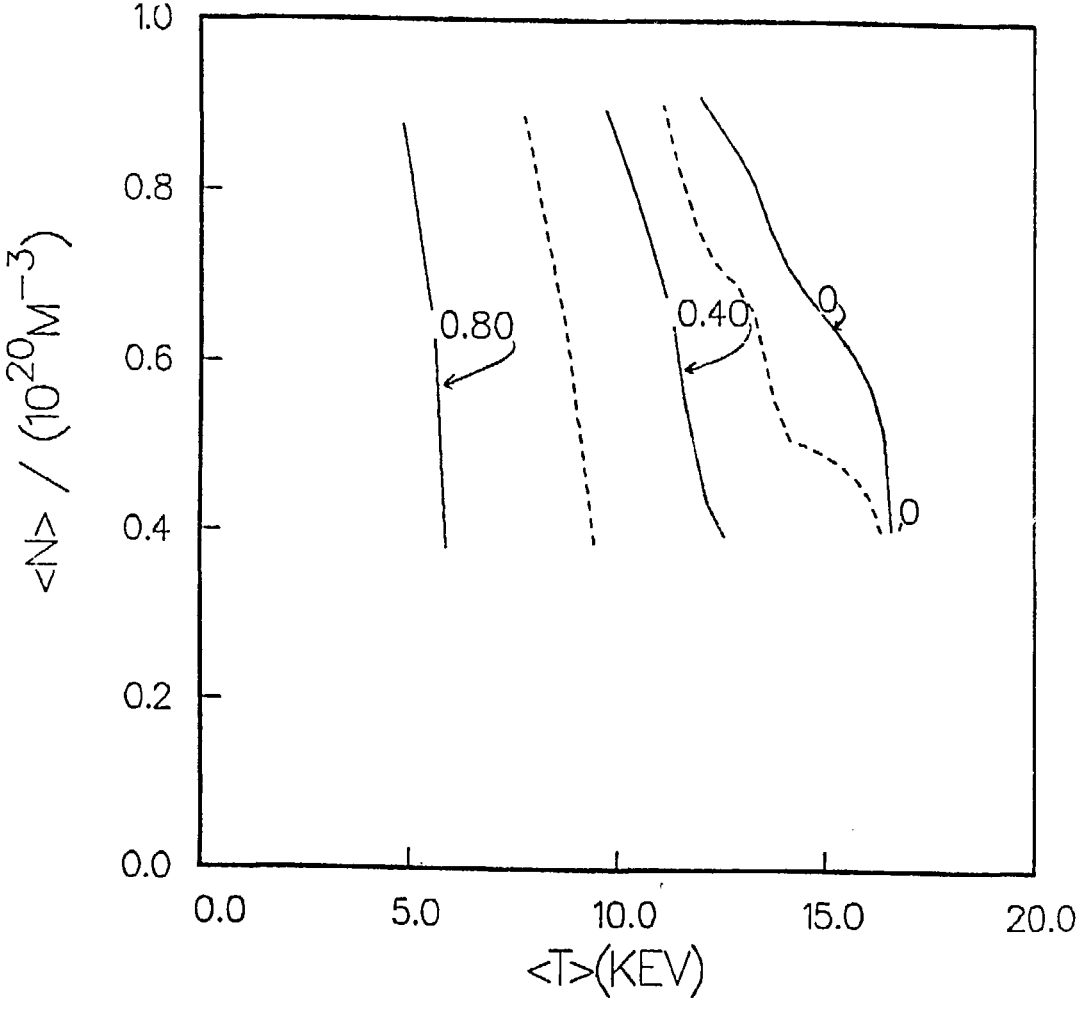


AUXILIARY POWER VS TEMPERATURE AND DENSITY

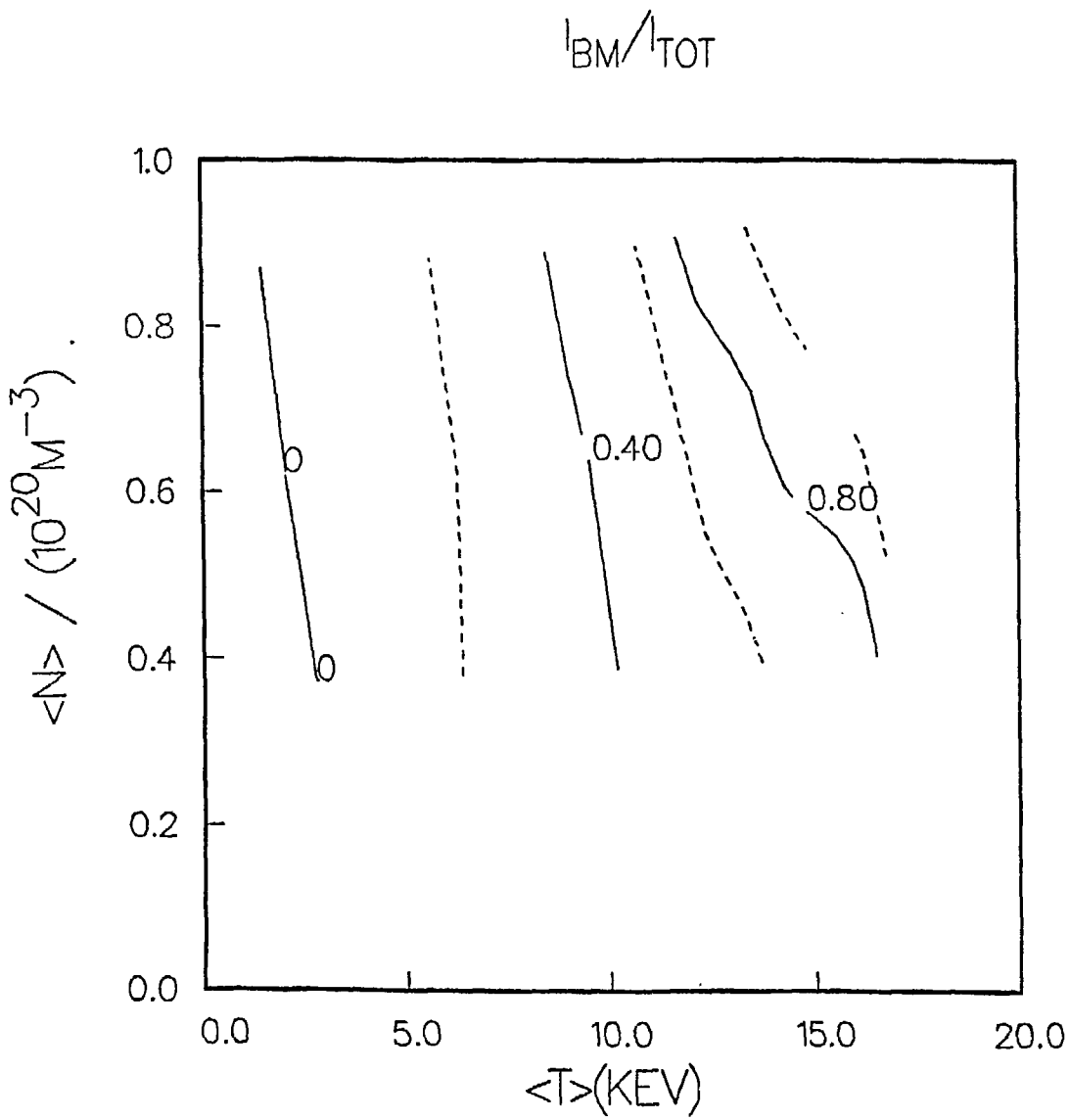


5

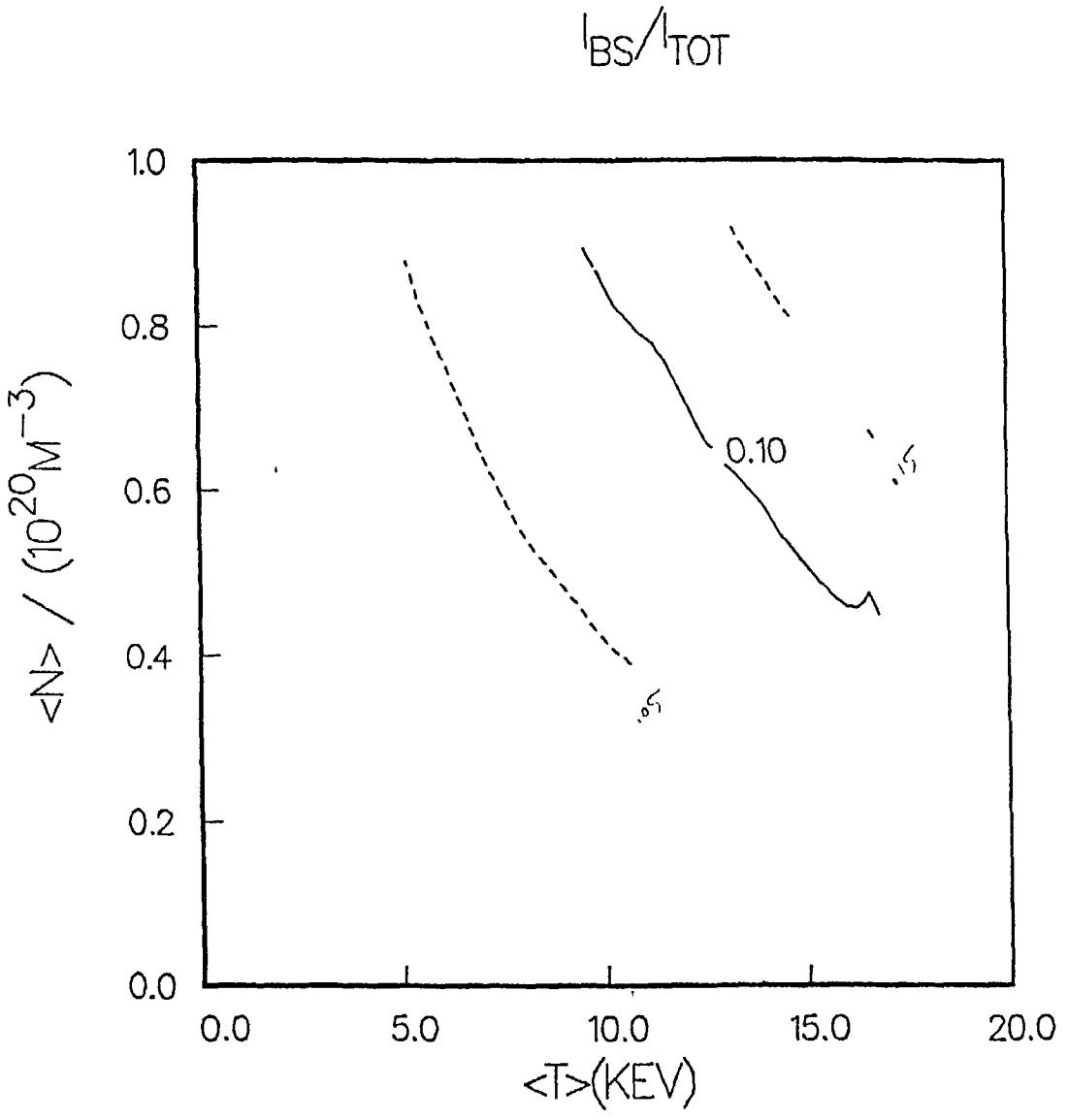
FRACTION OF CURRENT SUPPLIED INDUCTIVELY



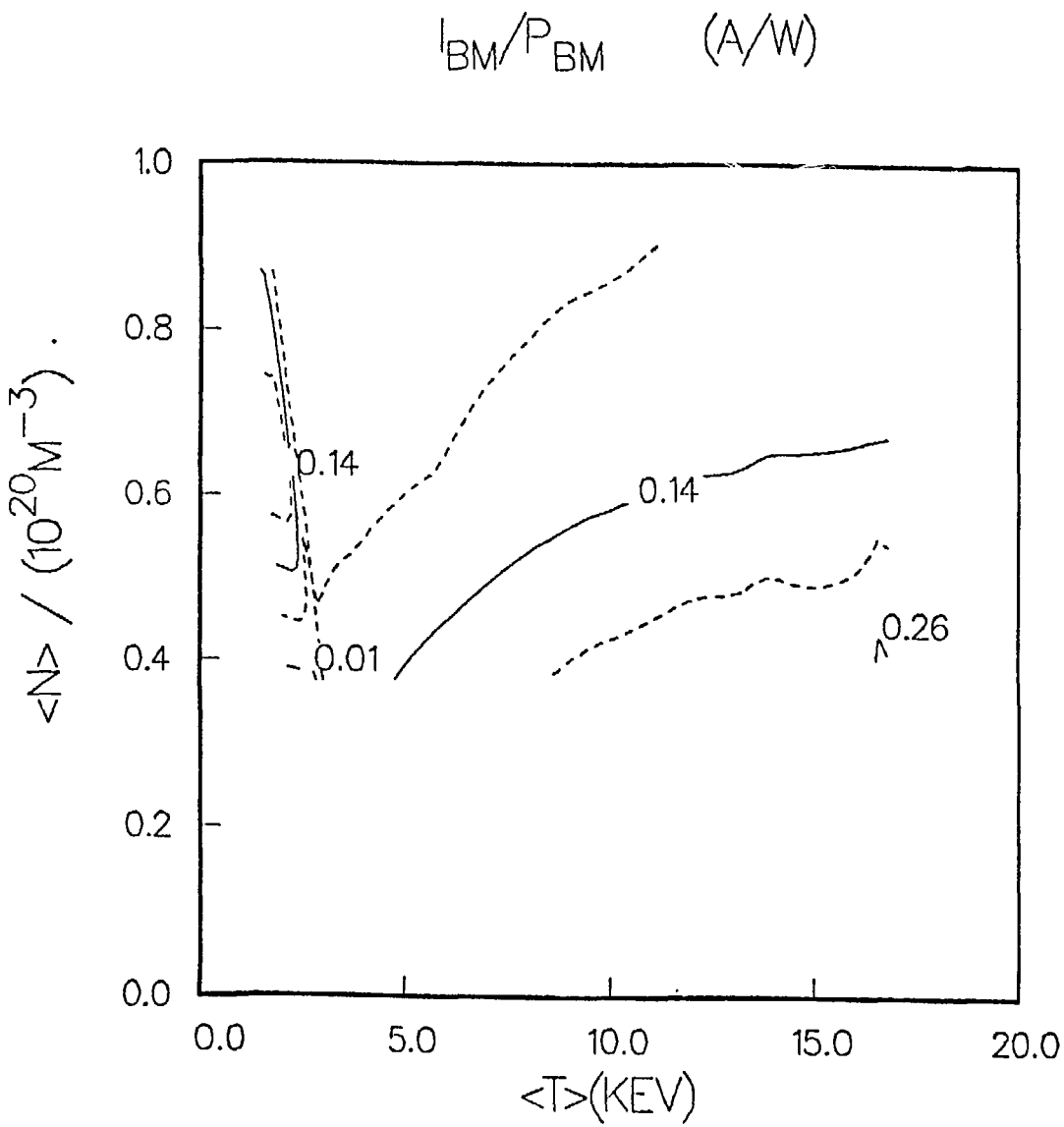
16


I_{BM}/I_{TOT}
1.0
0.8
0.6
0.4
0.2
0.0
0
0
0.40
0.80
0.0
5.0
10.0
15.0
20.0
<T>(KEV)
<N> / ($10^{20}M^{-3}$)

7


I_{BS}/I_{TOT}
1.0
0.8
0.6
0.4
0.2
0.0
0.10
.05
.15
0.0
5.0
10.0
15.0
20.0
<T>(KEV)
<N> / ($10^{20}M^{-3}$)

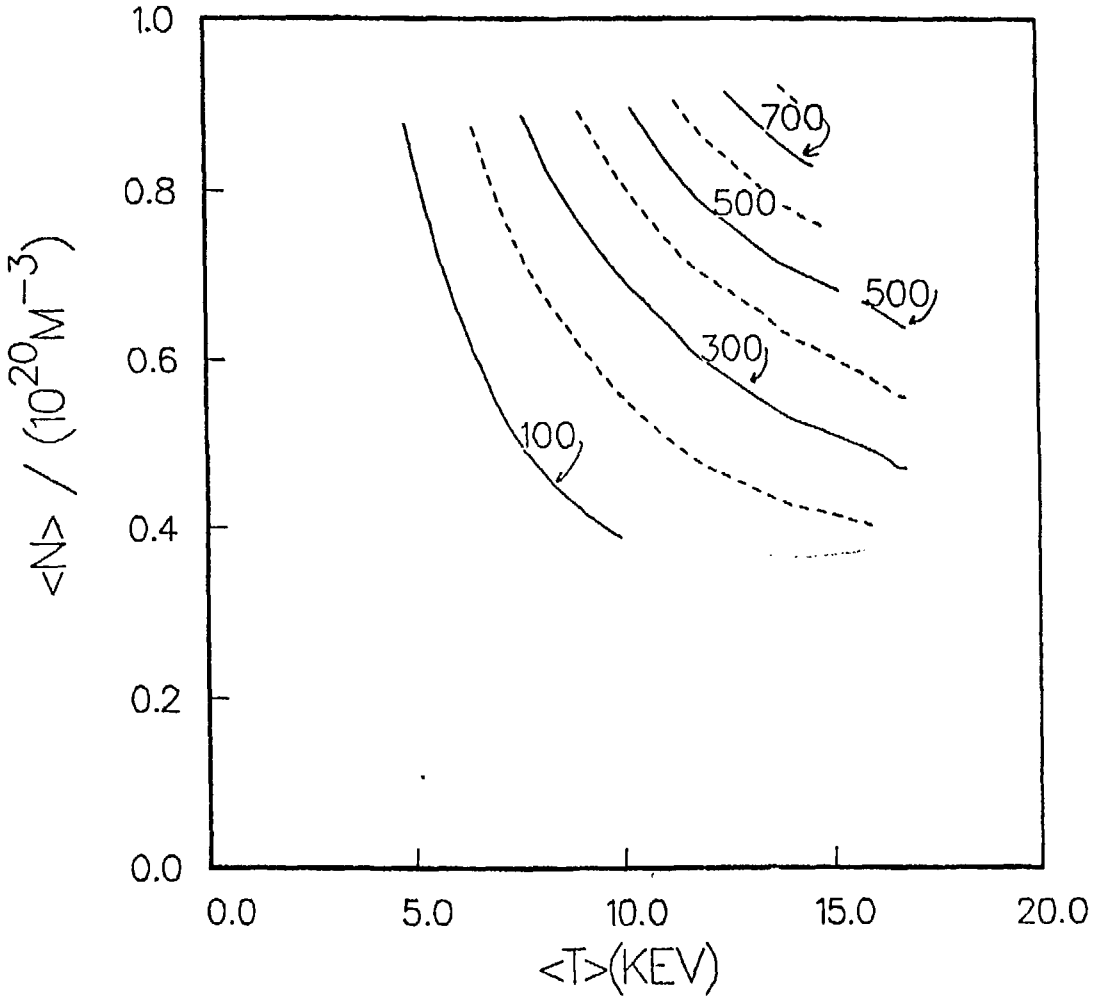
(8)


I_{BM}/P_{BM} (A/W)
1.0
0.8
0.6
0.4
0.2
0.0
<N> / ($10^{20}M^{-3}$)
0.14
0.01
0.14
0.26
0.0
5.0
10.0
15.0
20.0
<T>(KEV)

9

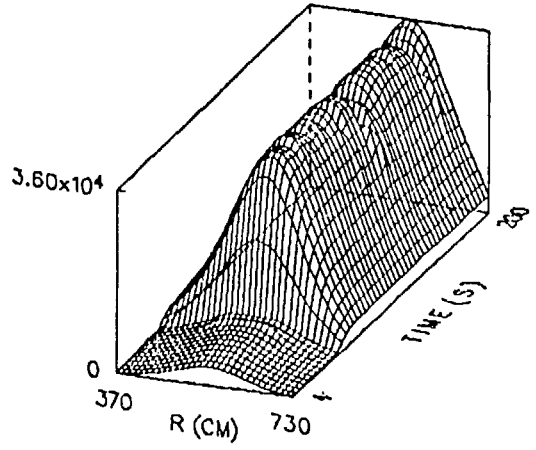
431

TOTAL FUSION POWER (MW)

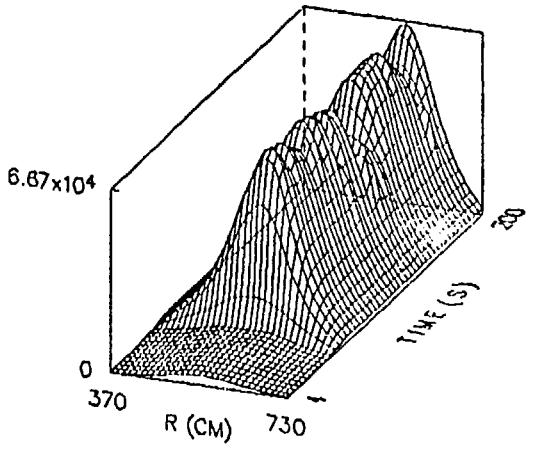


10

ELECTRON TEMP. (EV)

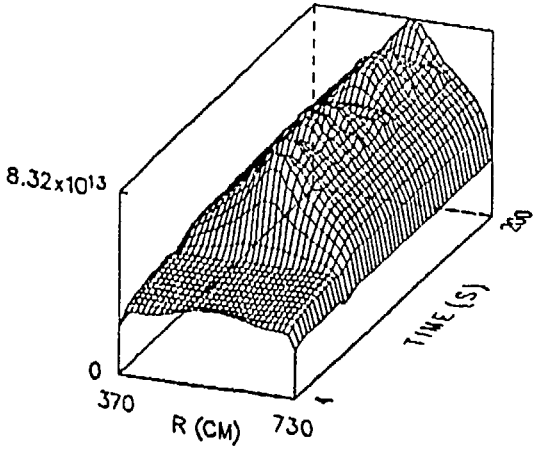


ION TEMP. (EV)

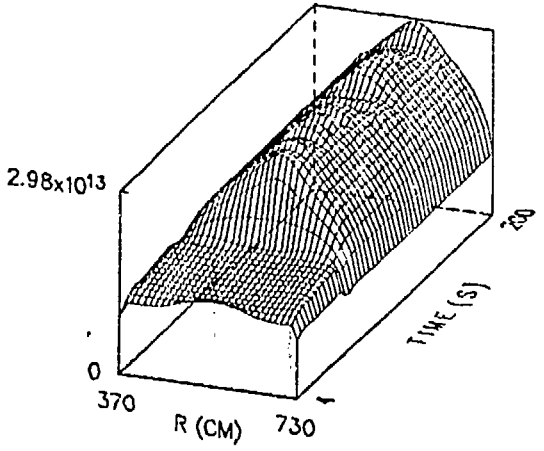


(11)

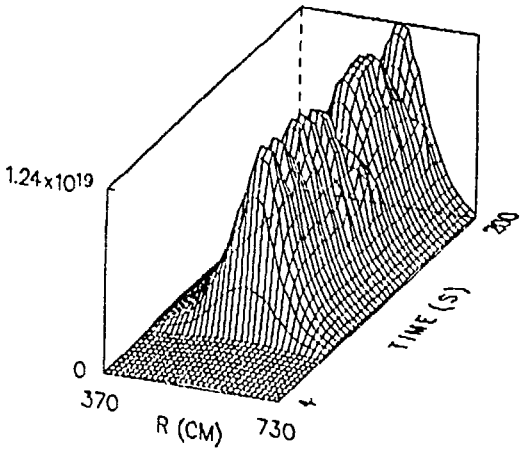
ELECTRON DENS(/CM3)



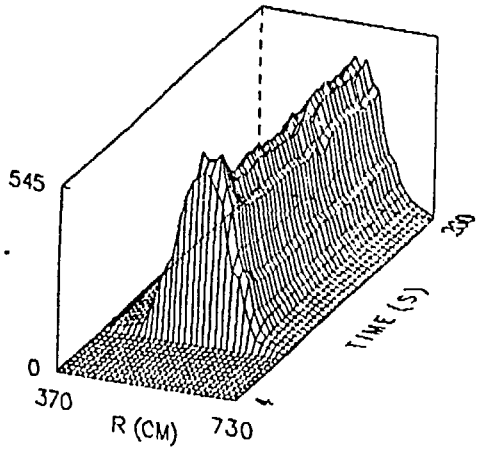
ION DENS(D) (/CM3)



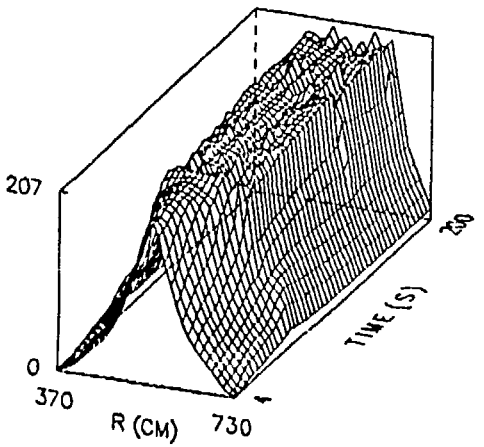
PRESSURE



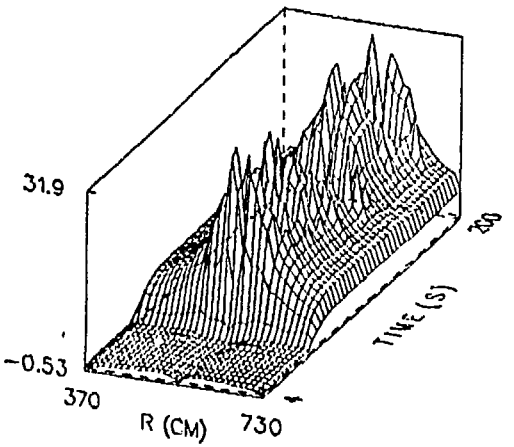
J BEAM



J TOTAL

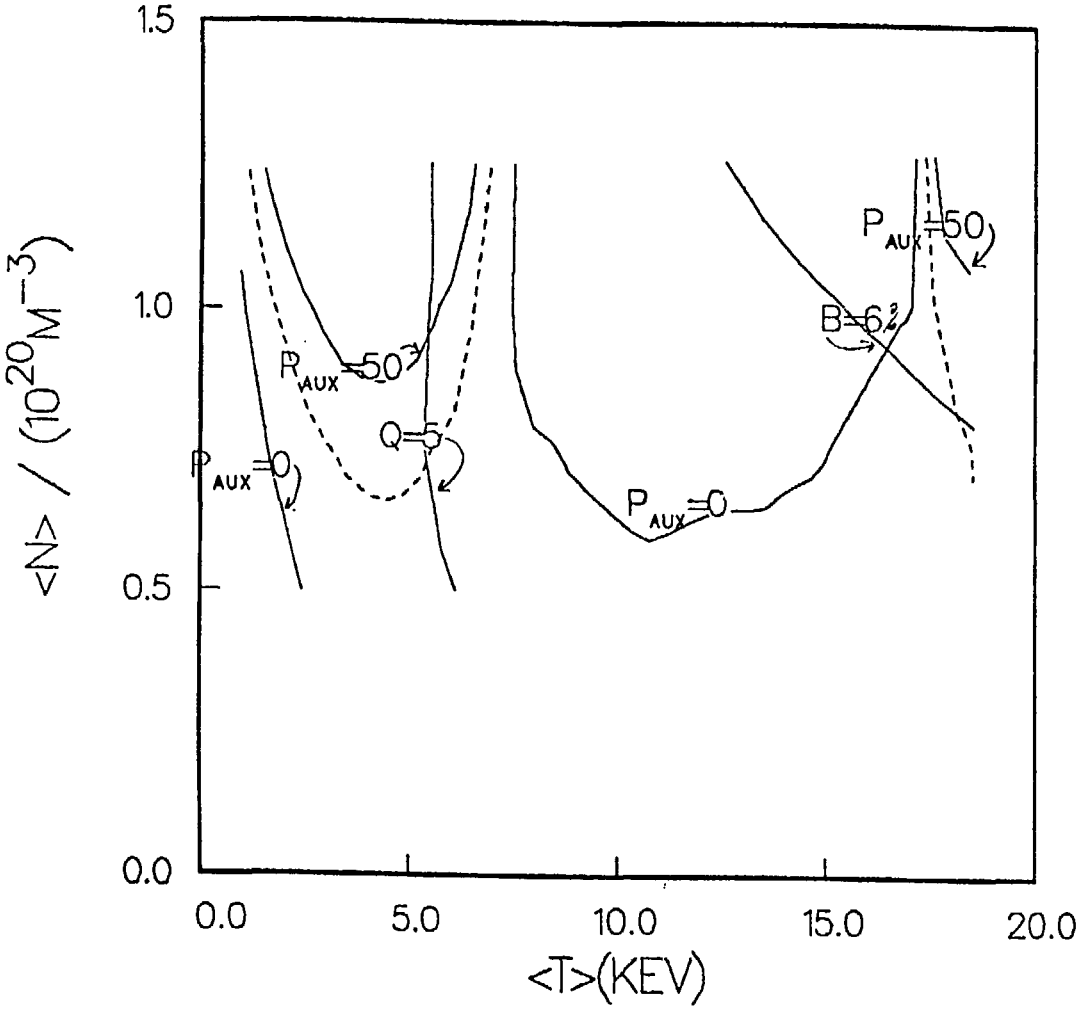


J BOOT



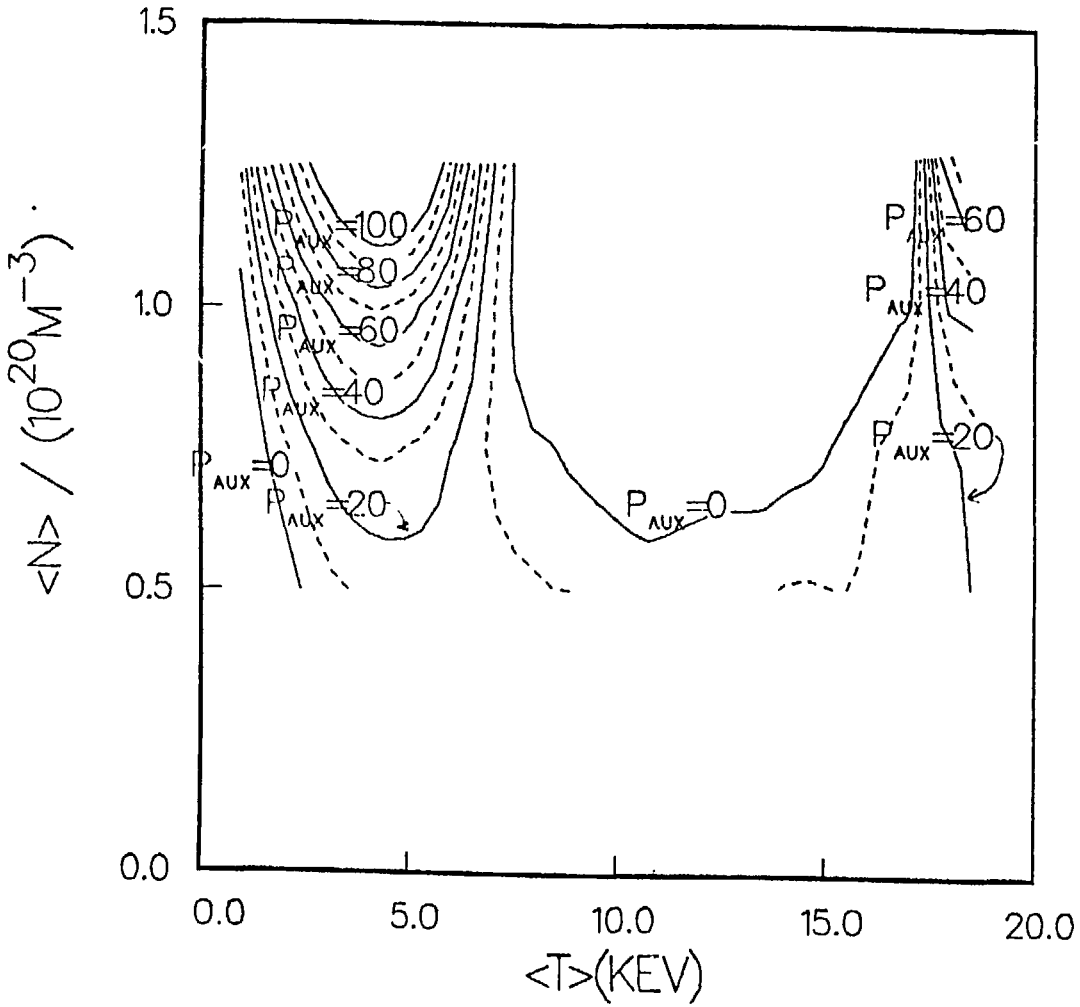
(12)

OPERATING REGION



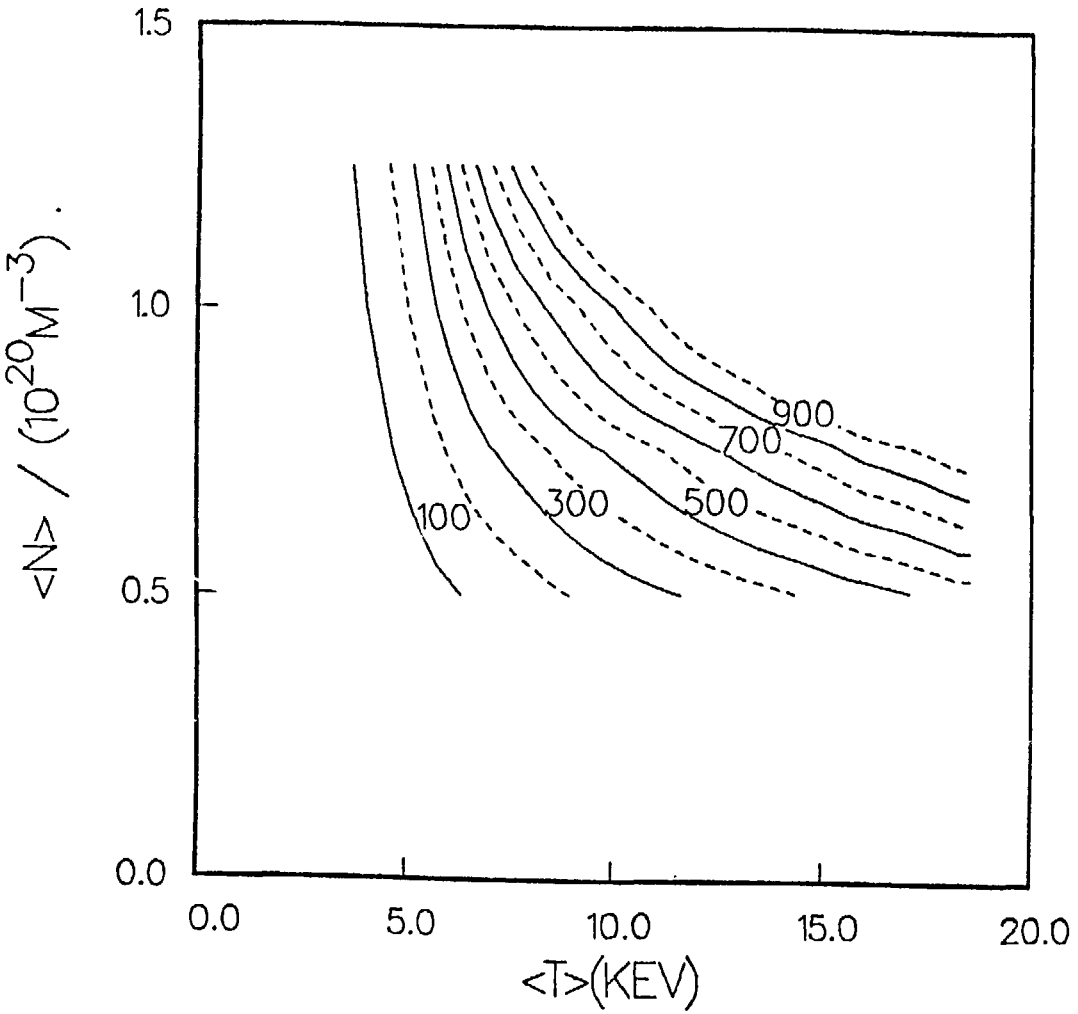
13

AUXILIARY POWER VS TEMPERATURE AND DENSITY



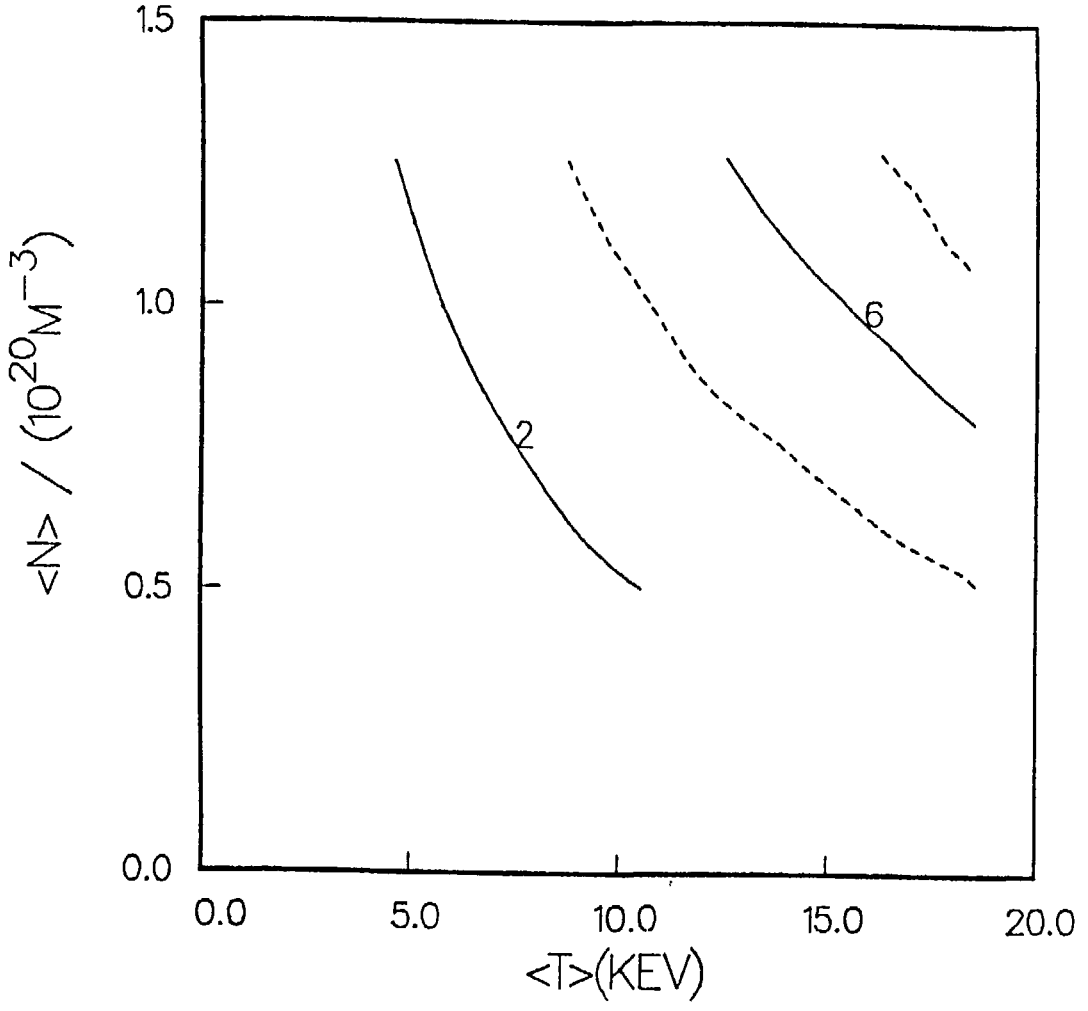
14

TOTAL FUSION POWER (MW)



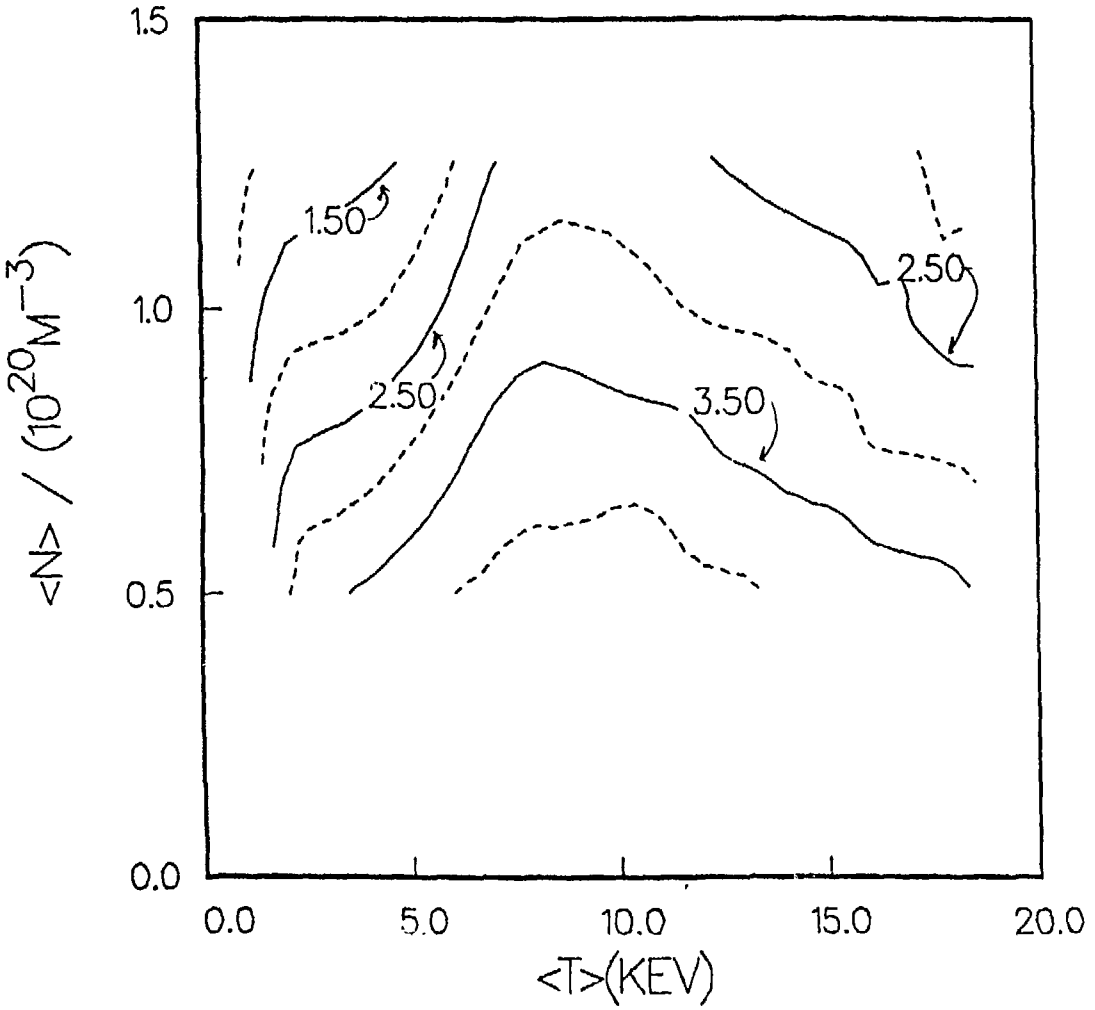
(15)

TOROIDAL BETA (%)

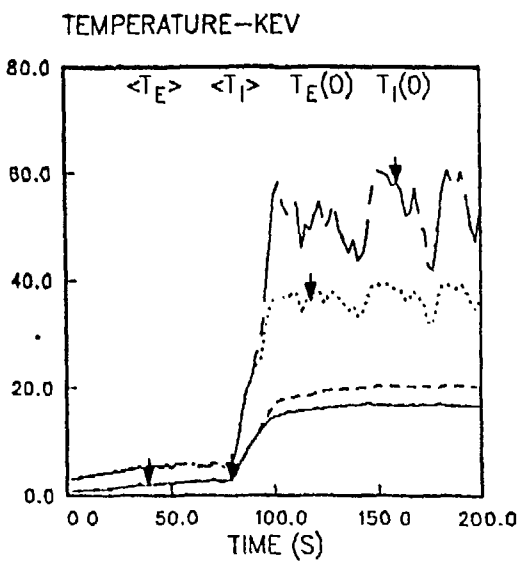


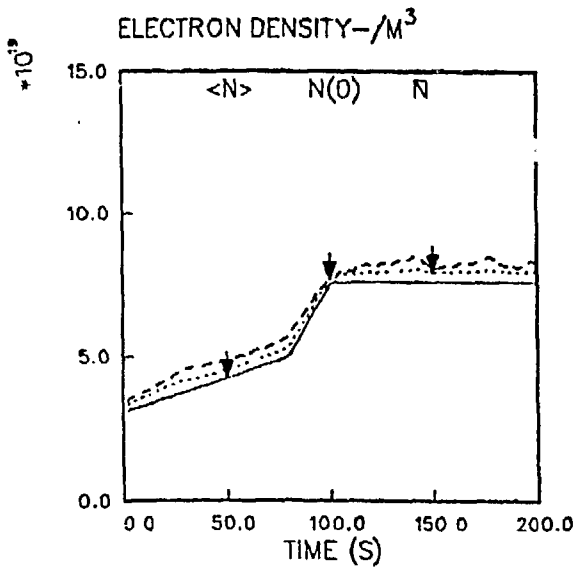
1b

ENERGY CONFINEMENT TIME (S)

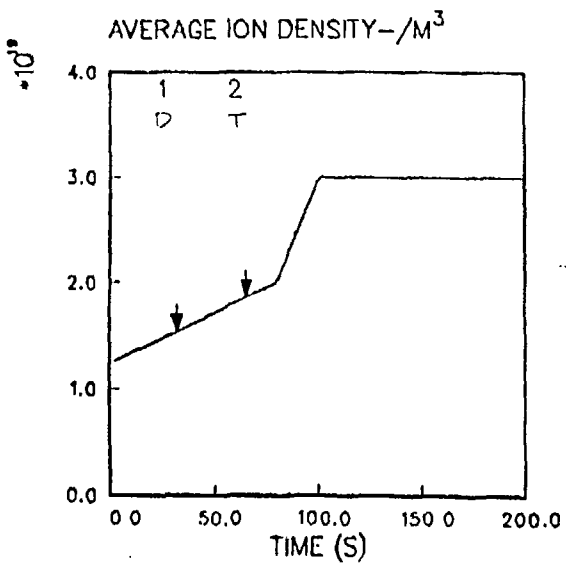


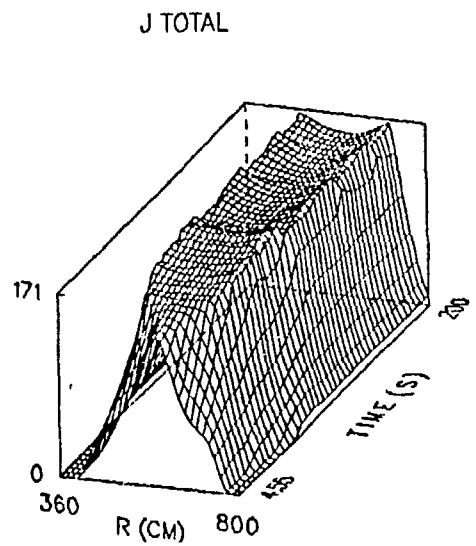
17


TEMPERATURE–KEV
<T_E> <T_I> T_E(0) T_I(0)
80.0
60.0
40.0
20.0
0.0
0.0 50.0 100.0 150.0 200.0
TIME (S)

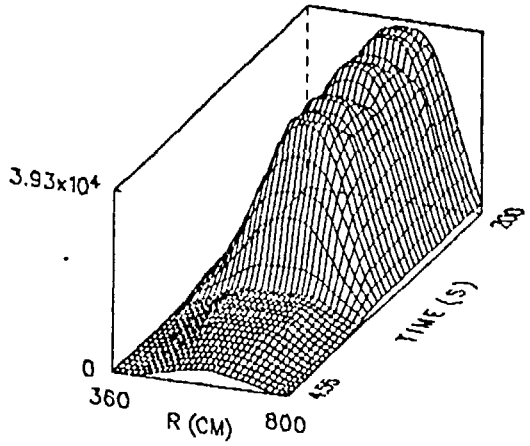

ELECTRON DENSITY–/M^3
*10^19
<N> N(0) N̄
15.0
10.0
5.0
0.0
0.0 50.0 100.0 150.0 200.0
TIME (S)

(18)

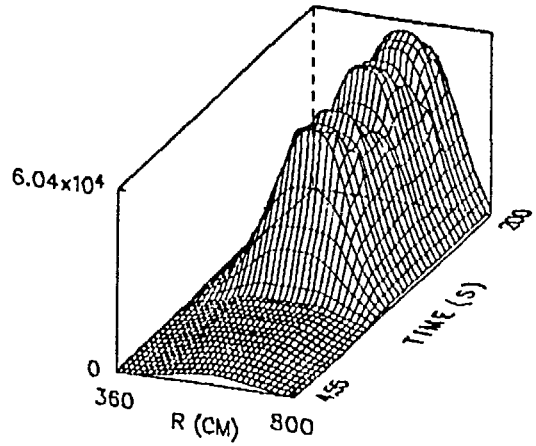

AVERAGE ION DENSITY–/M^3
*10^19
1 D
2 T
4.0
3.0
2.0
1.0
0.0
0.0 50.0 100.0 150.0 200.0
TIME (S)


J TOTAL
171
0
360
R (CM)
800
TIME (S)

ELECTRON TEMP. (EV)

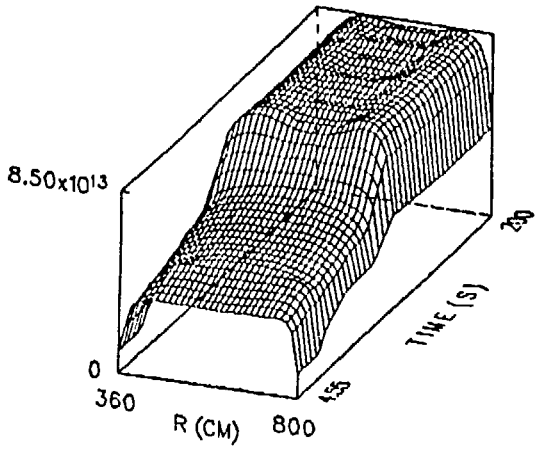


ION TEMP. (EV)

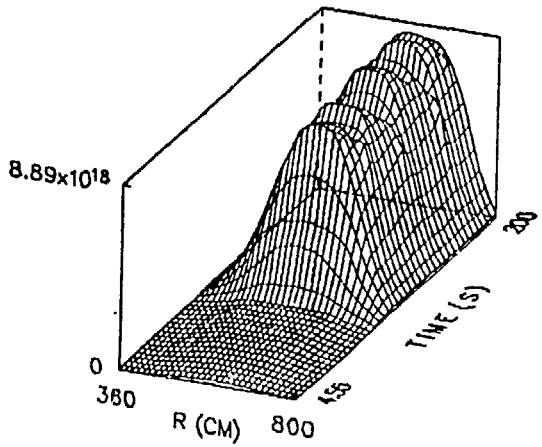


19

ELECTRON DENS(/CM3)

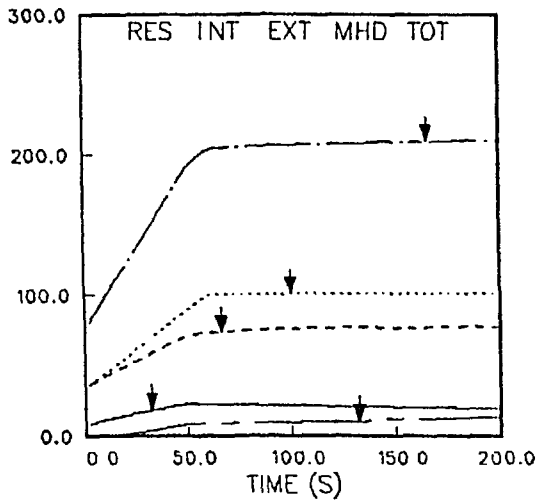


PRESSURE



ITER 5.5X1.8 M, 5.3 T, 18 MA (TECH. PHASE) 02221206(1)FC

POLOIDAL FLUX–V*S



20

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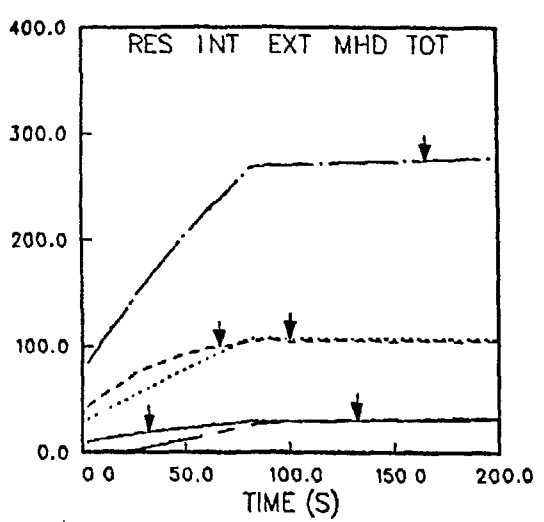
POLOIDAL FLUX–V*S