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IGNITION STUDIES*

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MASTER

A series of 1-1/2-D transport calculations have recently been performed for FED parameters and implications made for INTOR through comparison of the parameters. The effects of the flux surface shift on neutral beam penetration and increased toroidal field ripple losses are included self-consistently through the evolving 2-D MHD equilibria in the WHIST transport code. The FED and INTOR parameters used in this discussion are given in Table I.

The plasma operation contours (POPCON plots) shown in Fugures 1-7 were generated from a series of time-dependent transport simulations each having constant volume-averaged deuterium and tritium densities maintained by feed-back on their respective pellet fueling sources. The deuterium and tritium density profiles differ, however, because of fueling from the deuterium beams. Build up of alpha particles was neglected in these cases. The average plasma thermal temperature is defined as

$$\langle T \rangle \equiv \frac{\int (n_e T_e + \sum_j n_i T_i) d^3 r}{2 \langle n_e \rangle}$$

where the summation is over thermal ions. If the temperature is ramped slowly (through feed back on the heating source) the plasma profiles remain near equilibrium values at all times and the thermal losses are near equilibrium losses. The cases shown in the figures used a 20 s ramp while 40 s cases differed only slightly.

Figure 1 shows the net thermal losses at each value of $\langle n_e \rangle$ and $\langle T \rangle$ for the ETF parameters shown in Table I. Since the plasma is being maintained at these values with neutral beam heating, these losses are effectively the

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neutral beam power level required to maintain the plasma with the given injection parameters. The transport model for this reference case is given by

$$\chi_e \frac{5 \times 10^{17}}{n_e} \text{ cm}^2/\text{s}$$

$$D = .2\ \chi_e$$

$$\chi_i = 2\chi_i^{NC} + \chi_i^{RIP}$$

where the ripple contributions to the ion thermal conductivity include both ripple trapped[1] and ripple plateau[2-3] losses. Note that with our choice of 150 keV beams injected nearly tangential to the inside of the plasma, a minimum of 30 MW of beam power is required for an optimal ramped density startup. An additional 20-30 MW would have to be provided for a startup time of about 5 s. Ignition occurs at an average density of just under 1.1×10^{14} cm^{-3}. The increased ripple losses for $\langle T \rangle \gtrsim 15$ keV are reflected in the increased supplementary power requirements. Since the toroidal field plays only a minor role in the power requirements while the q profile, ripple contours and plasma volume are close to the same for ETF and INTOR, the power requirements for similar INTOR beam parameters shouldn't differ significantly from those shown in Figure 1. The choice of 175 keV near normal injection for INTOR appears to put excessive emphasis on beam penetration for far from optimal startup sequences. The high power requirements at high $\langle n_e \rangle$ and low $\langle T \rangle$ in Figure 1 are indicative of poor beam penetration but this region can be avoided in the startup sequence.

The total fusion power output shown in Figure 2 is essentially the same for FED and INTOR parameters except FED calls for operation near the 200 MW contour while INTOR is near the 600 MW contour. For FED this means operating

in a driven state with $Q \approx 5$-8 as shown in Figure 3. INTOR could operate in a thermally stable ignited state with $\langle T \rangle \sim 13$ keV and $\langle n_e \rangle \approx 1.15 \times 10^{14}$ cm^{-3} determined by the intersection of the zero beam power and 600 MW fusion output contours, although the margin for ignition is very small with this transport model.

Figure 4 shows the average toroidal beta which includes beam and fast alpha contributions. In FED, 200 MW of thermal output corresponds to $\langle \beta \rangle \approx 6\%$ while in INTOR $\langle \beta \rangle \approx 5.3\%$ at the cited operating point because of the higher toroidal field. The average poloidal beta for FED is $\langle \beta_p \rangle \approx 1.8$ along the 200 MW thermal output contour while for INTOR parameters $\langle \beta_p \rangle \approx 2.2$ at about 600 MW thermal output. In both cases this translates to about half the aspect ratio for the respective devices.

Figures 6 and 7 show the central electron and ion temperatures respectively. Note that $T_e(o) > T_i(o)$ in the anticipated burn regimes for both FED and INTOR since ion ripple conduction losses dominate.

References

1. R. J. Goldston and H. H. Towner, Nucl. Fusion 20 (1980) 781.
2. A. Boozer, "Enhanced Transport in Tokamaks due to Toroidal Ripple," PPPL-1619 (1980).
3. R. J. Goldston and H. H. Towner, "Effects of Toroidal Field Ripple on Supra-thermal Ions in Tokamak Plasmas," PPPL-1637 (1980).

TABLE I

	FED	INTOR
a(m)	1.3	1.2
R_o(m)	4.8	5.3
b/a	1.6	1.6
B_T (T)	3.6	5.5
I (MA)	5.7	6.4
E_D^o (keV)	150	175
Beam Current Mix	60:25:15	
Beam Tangency Radius (m)	3.6	
Ripple at edge (%)	.75	.75
TF coils	10	10

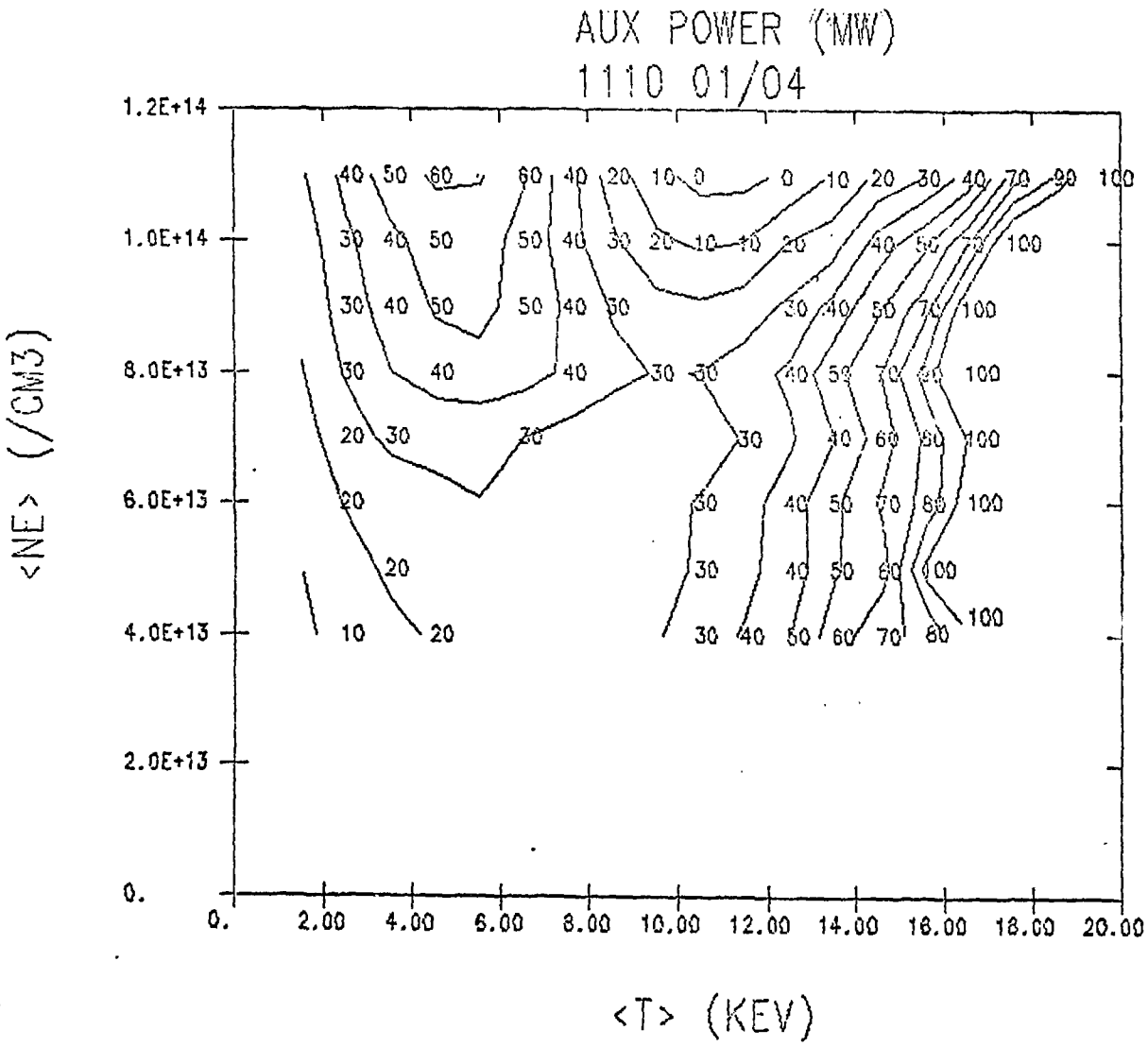
AUX POWER (MW)
1110 01/04
1.2E+14
1.0E+14
8.0E+13
6.0E+13
4.0E+13
2.0E+13
0.
<NE> (/CM3)
0.
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
<T> (KEV)

Figure 1

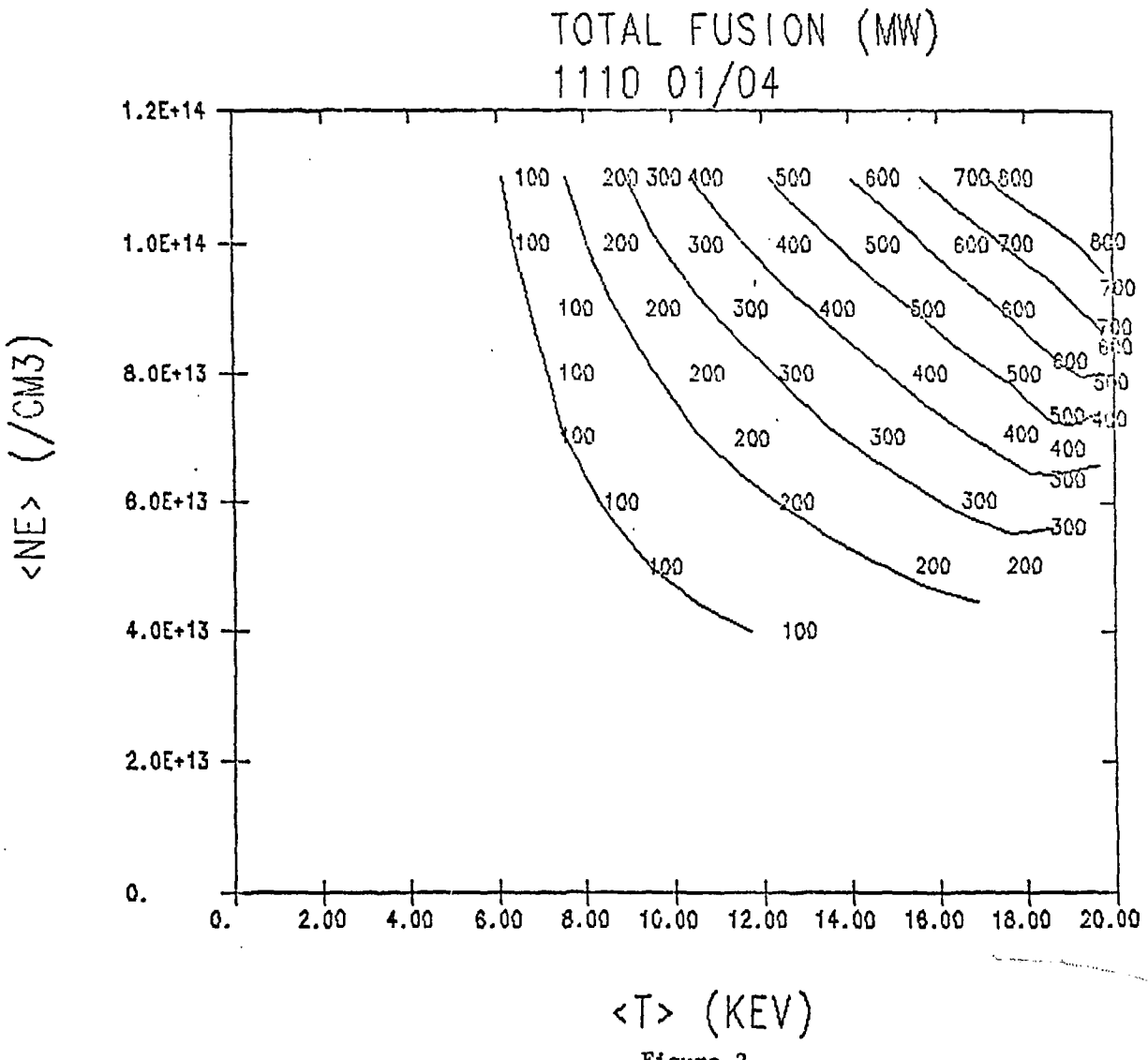
TOTAL FUSION (MW)
1110 01/04
1.2E+14
1.0E+14
8.0E+13
6.0E+13
4.0E+13
2.0E+13
0.
<NE> (/CM3)
0.
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
<T> (KEV)

Figure 2

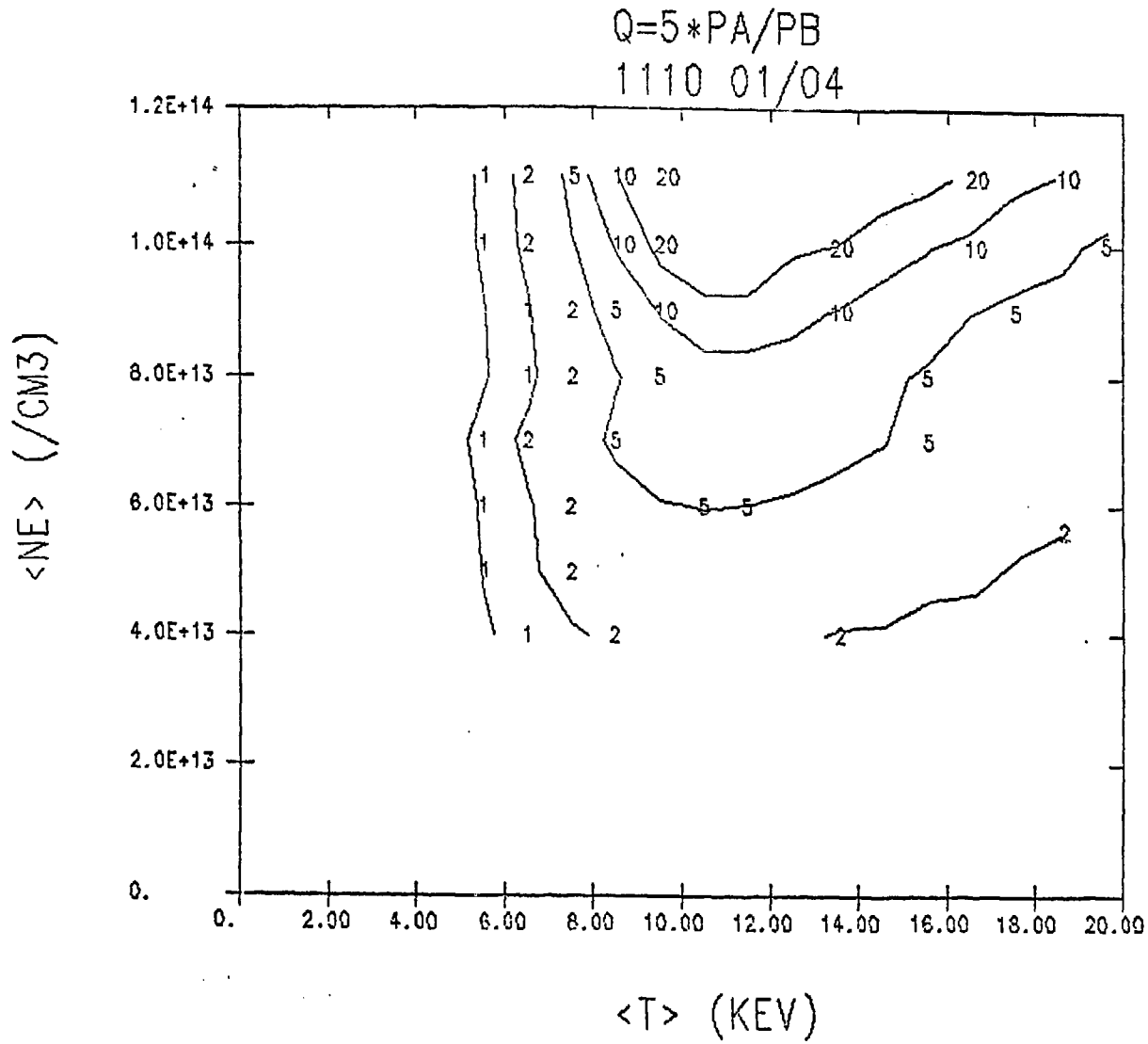
Q=5*PA/PB
1110 01/04
1.2E+14
1.0E+14
8.0E+13
6.0E+13
4.0E+13
2.0E+13
0.
<NE> (/CM3)
0.
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
<T> (KEV)

Figure 3

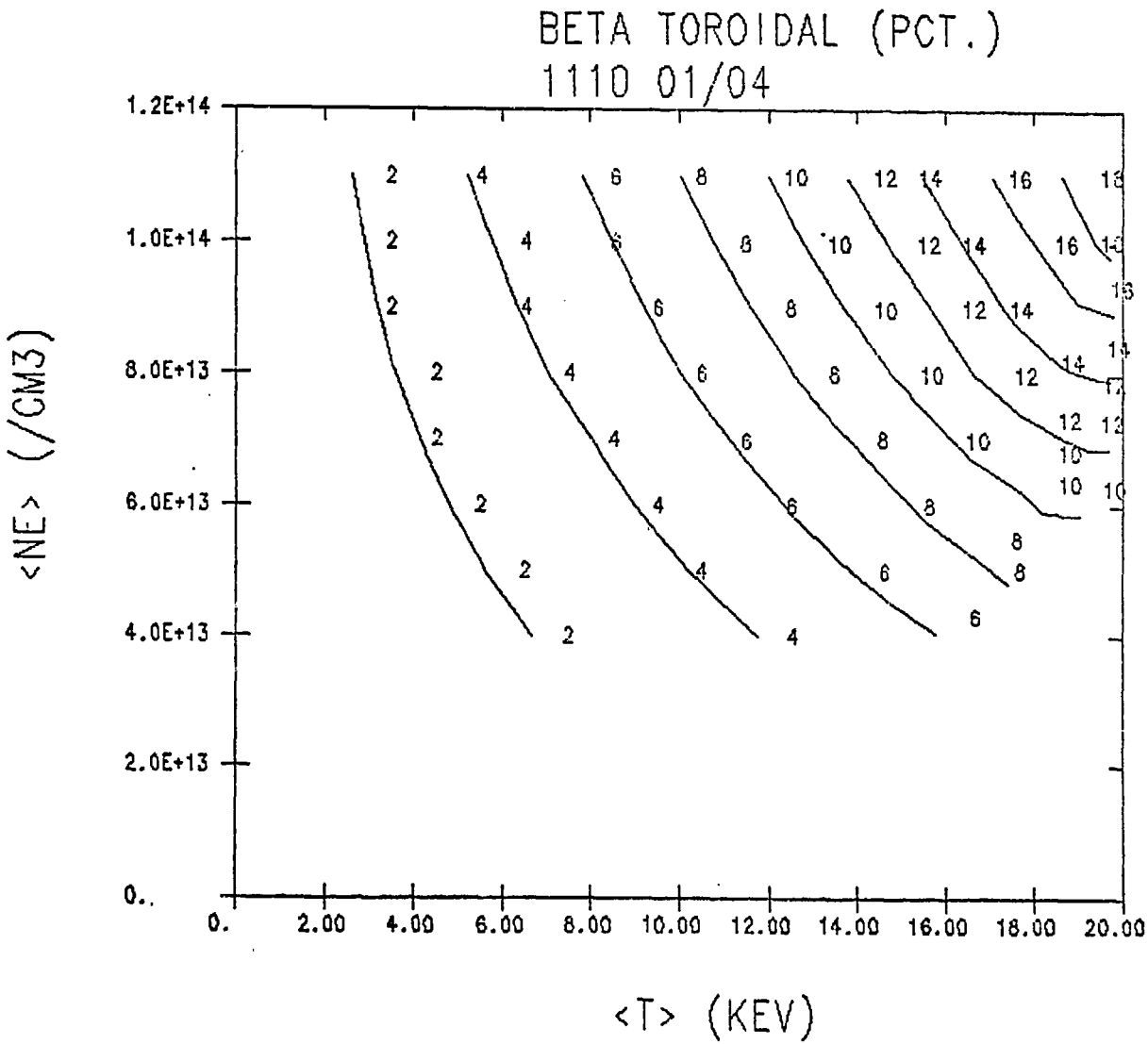
BETA TOROIDAL (PCT.)
1110 01/04
1.2E+14
1.0E+14
8.0E+13
6.0E+13
4.0E+13
2.0E+13
0.
<NE> (/CM3)
0.
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
<T> (KEV)

Figure 4

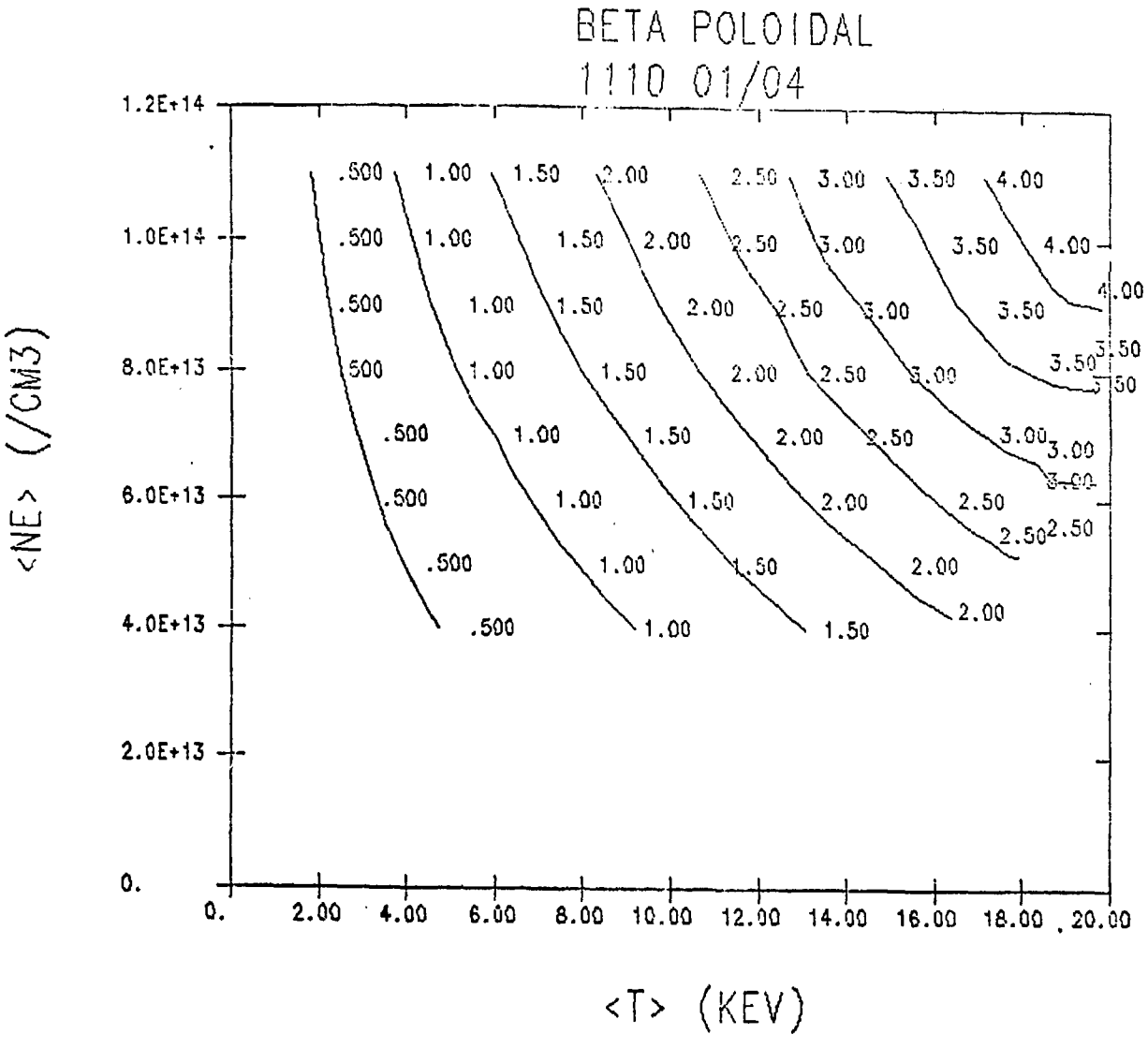
BETA POLOIDAL
1110 01/04
1.2E+14
1.0E+14
8.0E+13
6.0E+13
4.0E+13
2.0E+13
0.
<NE> (/CM3)
0.
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
<T> (KEV)
.500
1.00
1.50
2.00
2.50
3.00
3.50
4.00

Figure 5

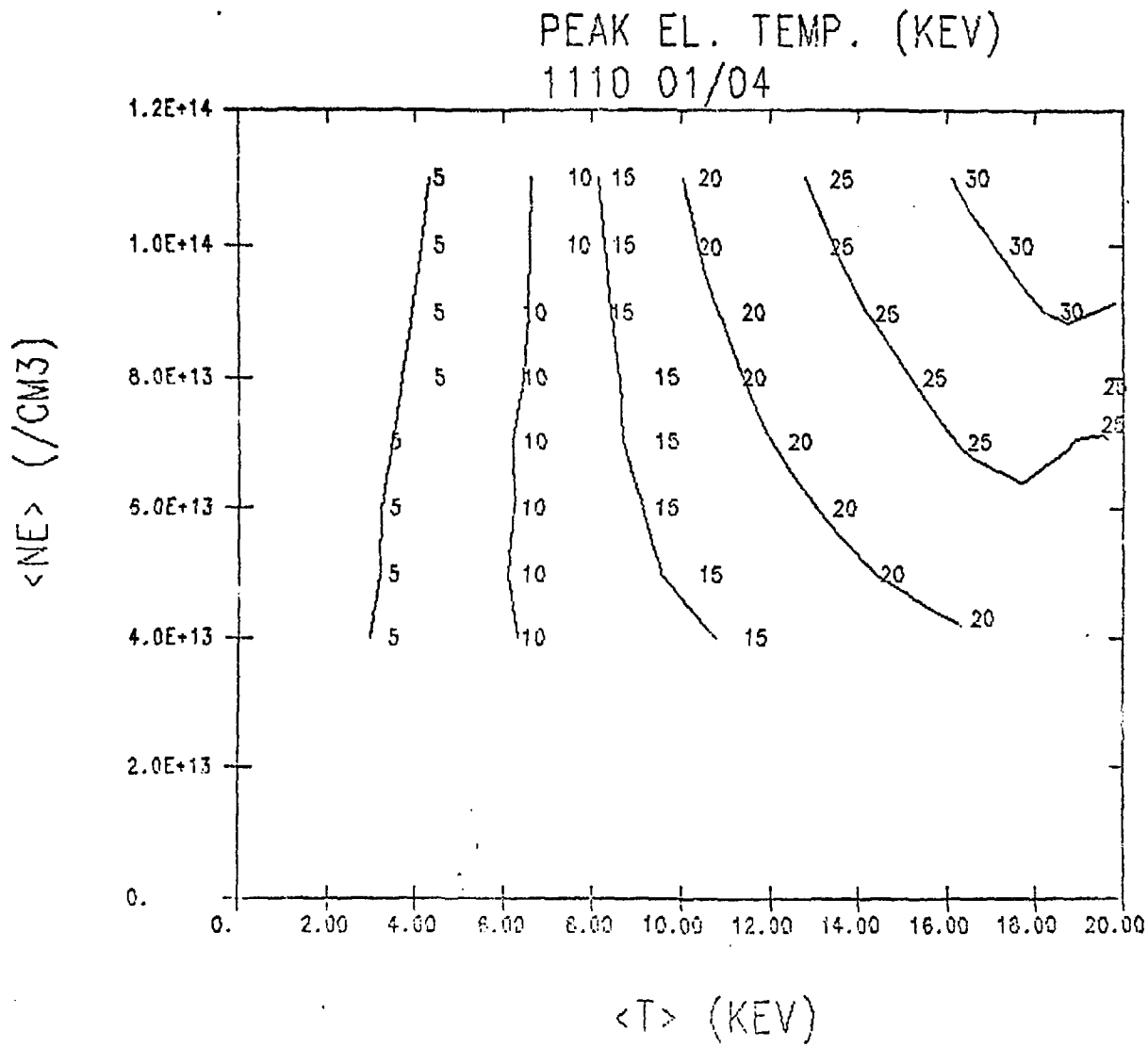
PEAK EL. TEMP. (KEV)
1110 01/04
1.2E+14
1.0E+14
8.0E+13
6.0E+13
4.0E+13
2.0E+13
0.
<NE> (/CM3)
0.
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
<T> (KEV)

Figure 6

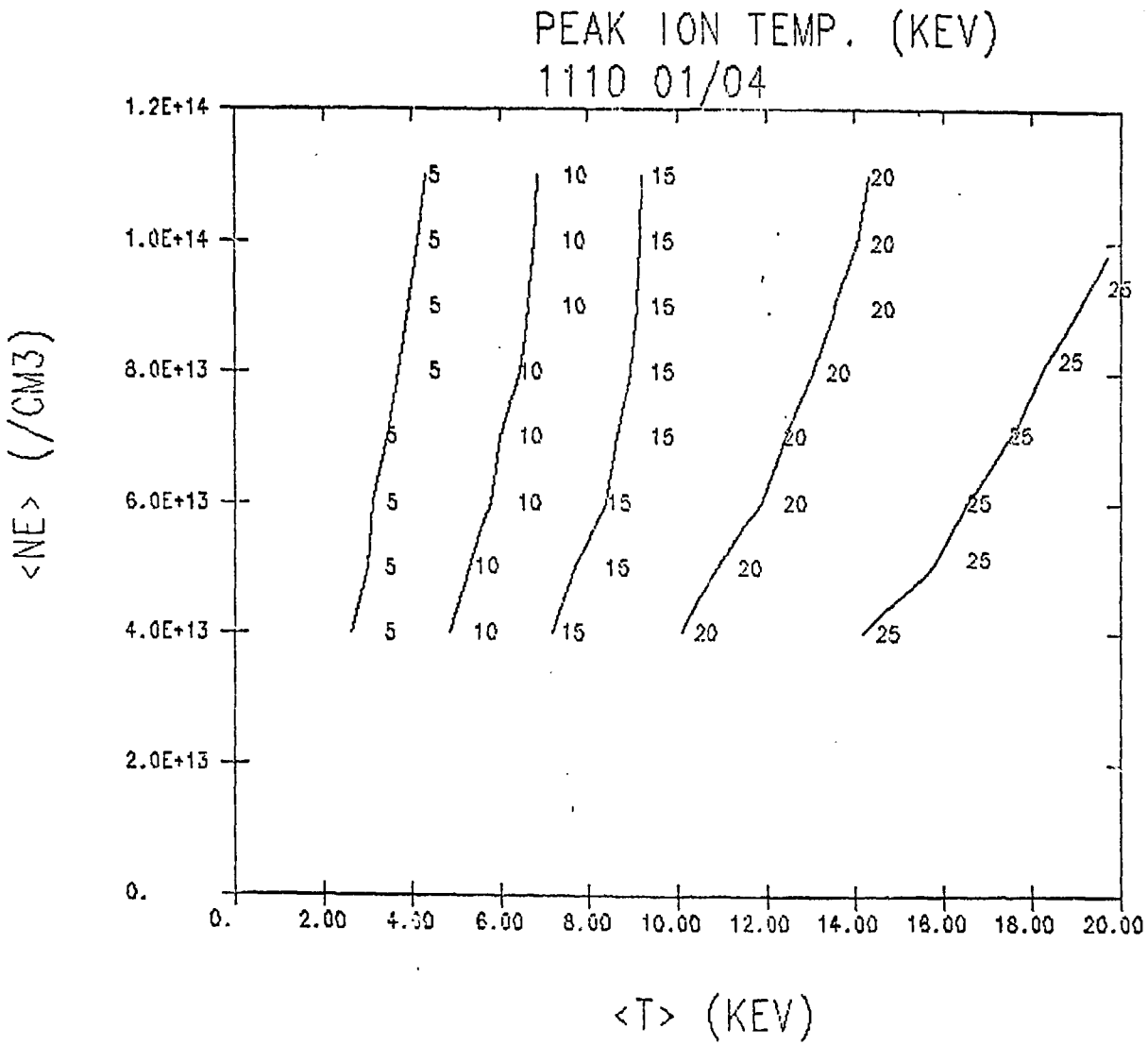
PEAK ION TEMP. (KEV)
1110 01/04
<NE> (/CM3)
1.2E+14
1.0E+14
8.0E+13
6.0E+13
4.0E+13
2.0E+13
0.
0.
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
<T> (KEV)
5
10
15
20
25

Figure 7