IDEAL-MHD STABILITY STUDIES AND ISSUES FOR ADVANCED TOKAMAK OPERATION

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"ADVANCED TOKAMAK" CONCEPT

STEADY STATE, NON-INDUCTIVE CURRENT.

HIGH β_p FOR HIGH BOOTSTRAP CURRENT FRACTION AND OPERATION IN BALLOONING SECOND STABILITY REGION.

$q_{min} > 2$ FOR GLOBALLY STABLE ACCESS TO S.S.R. AND SUPPRESSION OF LOW-m INTERNAL MODES.

HOLLOW q-PROFILE FOR INTERNAL TRANSPORT BARRIER AND HIGHER I AT $q_{min} > 2$.

PROPOSED APPROACH

RELY ON CURRENT AND DENSITY PROFILE CONTROL TO OPERATE IN THE "ADVANCED TOKAMAK" REGIME AT FUSION RELEVANT VALUES OF β AND I.

REMAIN STABLE AGAINST ALL MACROSCOPIC MHD MODES WITHOUT ANY CONDUCTING WALL (EXCEPT FOR $n=0$). THEN THE STABILITY LIMIT IS SET BY THE $n=1$ EXTERNAL MODE.

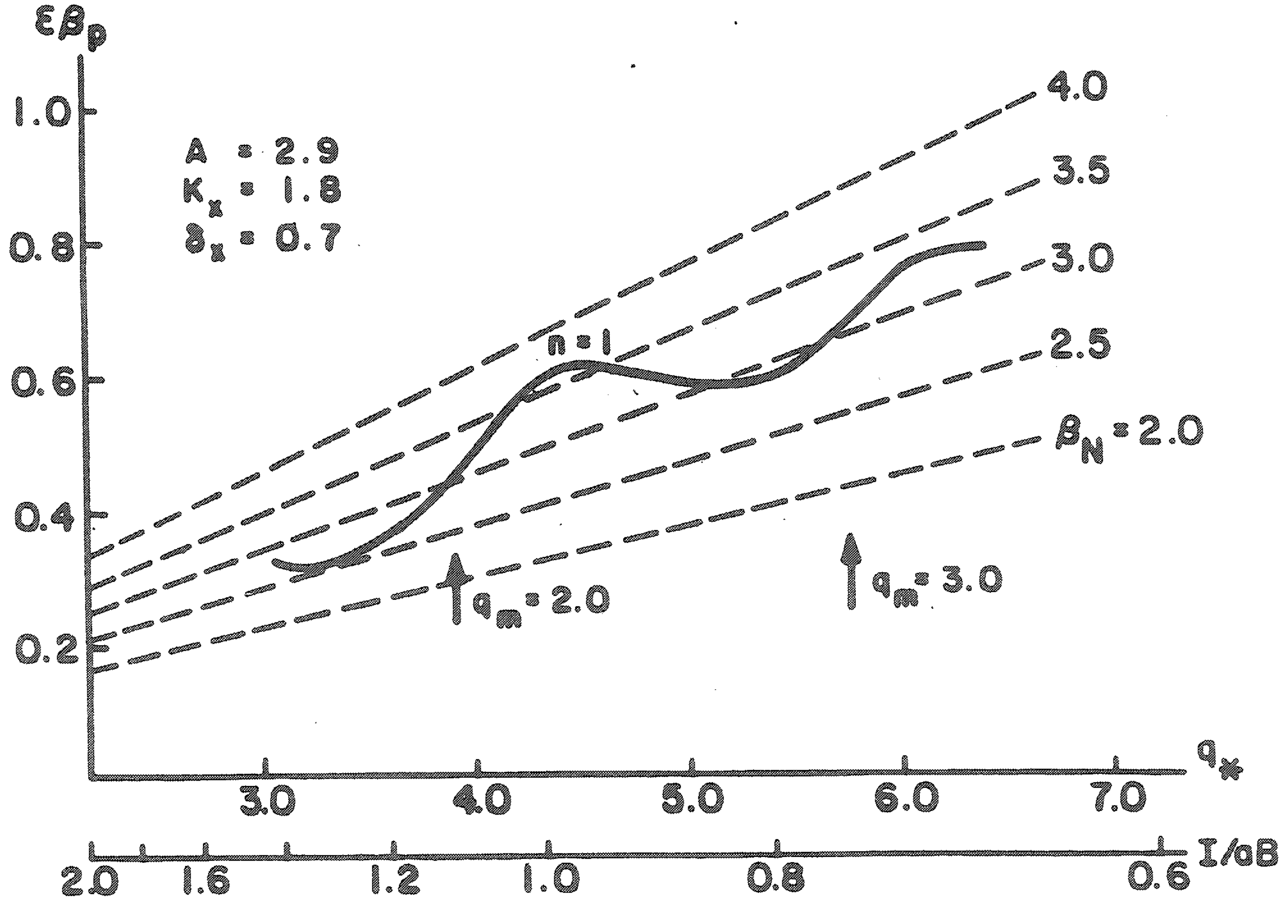
PREVIOUS WORK (BONOLI, PORKOLAB, RAMOS, NEVINS & KESSEL, PLASMA PHYS. CONTR. FUSION <u>39</u>, 22 (1997)) HAS IDENTIFIED AN ATTRACTIVE SET OF "A.T." PARAMETERS:

$\kappa \simeq 1.8$

$p_0 / p_{av} \simeq 2.6 - 2.8$

$q_{min} \simeq 2.2$ AT $r/a \simeq 0.7$

HERE WE SHALL INVESTIGATE THE EFFECTS OF A, δ AND I (OR q_a).



BONOLI, PORKOLAB, RAMOS, NEVINS & KESSEL, PLASMA PHYS. CONTR. FUSION 39, 22 (1997)

"PARAMETRIC STUDY OF MHD STABILITY LIMITS IN THE ADVANCED TOKAMAK" REGIME

HELD FIXED:

$p(\hat{\psi})/P_0 = (1-\hat{\psi})^2 \longrightarrow P_0/P_{av} \simeq 2.6-2.8$

$q_0 \simeq 3.5$

$q_{min} = 2.2$ AT $\rho \simeq r/a \simeq 0.7$

$\kappa = 1.8$

VARIED:

$P_0 \longrightarrow \beta$

$I \longrightarrow q_a$

$A = 3.0,\ 4.0$

$\delta = 0.3,\ 0.4,\ 0.5$

NUMERICAL ANALYSIS WITH J-SOLVER AND PEST-II CODES

FOR COMPARISON OF THE BOOTSTRAP CURRENT FRACTIONS AT DIFFERENT VALUES OF β, I, A AND δ, f_{BS} IS EVALUATED FIRST IN THE LOW COLLISIONALITY REGIME ASSUMING THE FIXED TEMPERATURE AND DENSITY PROFILES:

$$T(\hat{\Psi})/T(0) = (1-\hat{\Psi})^{3/2}$$

$$n(\hat{\Psi})/n(0) = (1-\hat{\Psi})^{1/2}$$

COMPARISON OF n=1 STABILITY LIMITS AT CONSTANT $\delta = 0.4$

	A=4.0	A=3.0	A=4.0	A=3.0
A I(MA)/a(m) B(T)	4.0	4.0	3.0	3.0
I/aB	1.0	1.33	0.75	1.0
q_a	3.5	4.0	5.5	6.1
β_N	1.75	2.9	2.7	3.1
β	1.75%	3.9%	2.0%	3.1%
f_{bs}	0.36	0.50	0.61*	0.60*
AI/aB	3.72		2.83	
I/aB	0.93		0.71	
q_a	4.0		6.1	
β_N	2.6		2.8	
β	2.4%		2.0%	
f_{bs}	0.54		**	

*: BOOTSTRAP CURRENT EQUALS EQUILIBRIUM CURRENT LOCALLY WITHOUT EXCEEDING IT

**: BOOTSTRAP CURRENT EXCEEDS EQUILIBRIUM CURRENT. NEGATIVE CURRENT DRIVE REQUIRED.

COMPARISON OF n=1 STABILITY LIMITS AT CONSTANT A=3.0

	$\delta = 0.3$	$\delta = 0.4$	$\delta = 0.5$
AI/a B			3.27
I/aB			1.09
q_a			6.1
β_N			3.1
β			3.4%
f_{bs}			0.57
AI/aB	3.0	3.0	3.0
I/aB	1.0	1.0	1.0
q_a	5.5	6.1	7.0
β_N	2.85	3.1	3.2
β	2.85%	3.1%	3.2%
f_{bs}	0.56*	0.60*	0.61*
AI/aB	2.82		2.65
I/aB	0.94		0.88
q_a	6.1		8.7
β_N	2.95		3.2
β	2.8%		2.8%
f_{bs}	**		**

FURTHER OPTIMIZATION OF BOOTSTRAP CURRENT FRACTION

VARY T AND n PROFILES WHILE KEEPING THEIR PRODUCT $nT = p$ CONSTANT, SO THAT MHD STABILITY RESULTS DO NOT CHANGE.

f_{BS} IS INCREASED BY PEAKING DENSITY PROFILE.

OPTIMIZED PROFILES FOR HIGH f_{bs}

$A = 3.0$

$\kappa = 1.8$

$\delta = 0.5$

$I/aB = 0.94$ MA/mT

$q_0 = 3.6$

$q_{min} = 2.2$

$q_a = 7.4$

$\beta_p = 1.6$

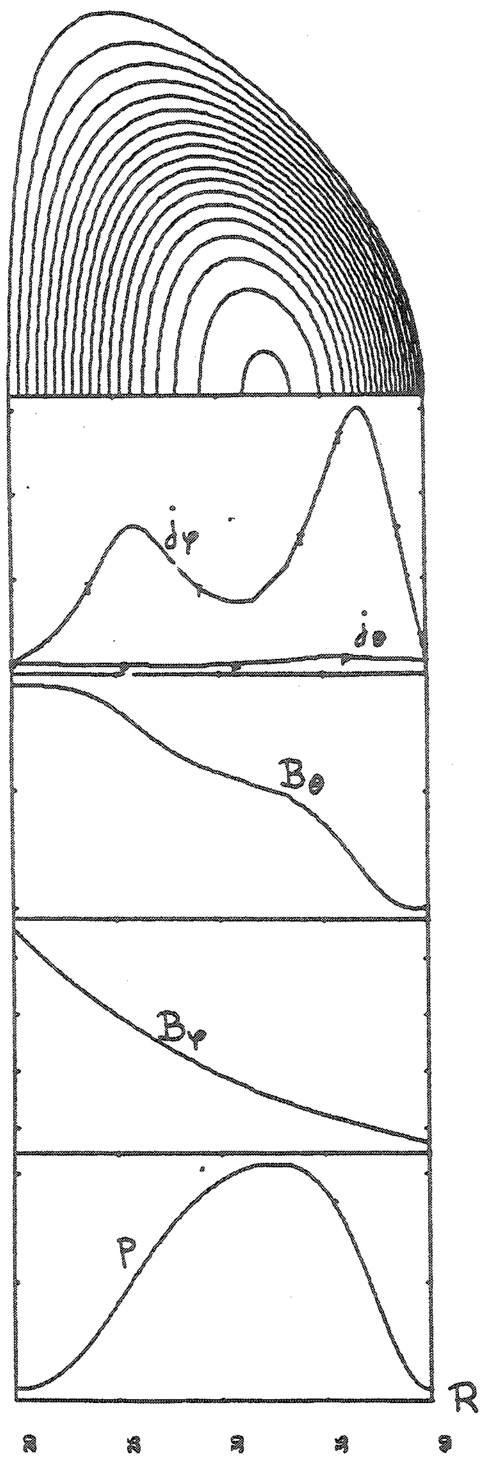
$\beta_N = 3.0$

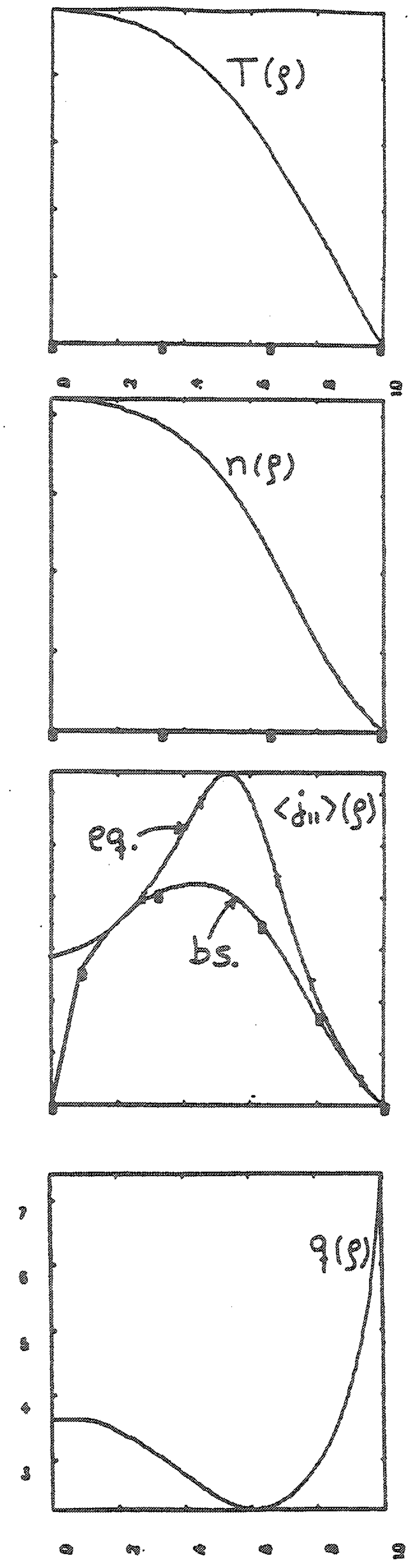
$\beta = 2.8\%$

$p_0/p_{av} = 2.9$

$l_i = 0.85$

$f_{bs} = 0.75$





OPTIMIZED PROFILES FOR HIGH f_{bs}

$A = 3.0$

$\kappa = 1.8$

$\delta = 0.5$

$I/aB = 1.09$ MA/mT

$q_0 = 3.4$

$q_{min} = 2.2$

$q_a = 6.1$

$\beta_p = 1.5$

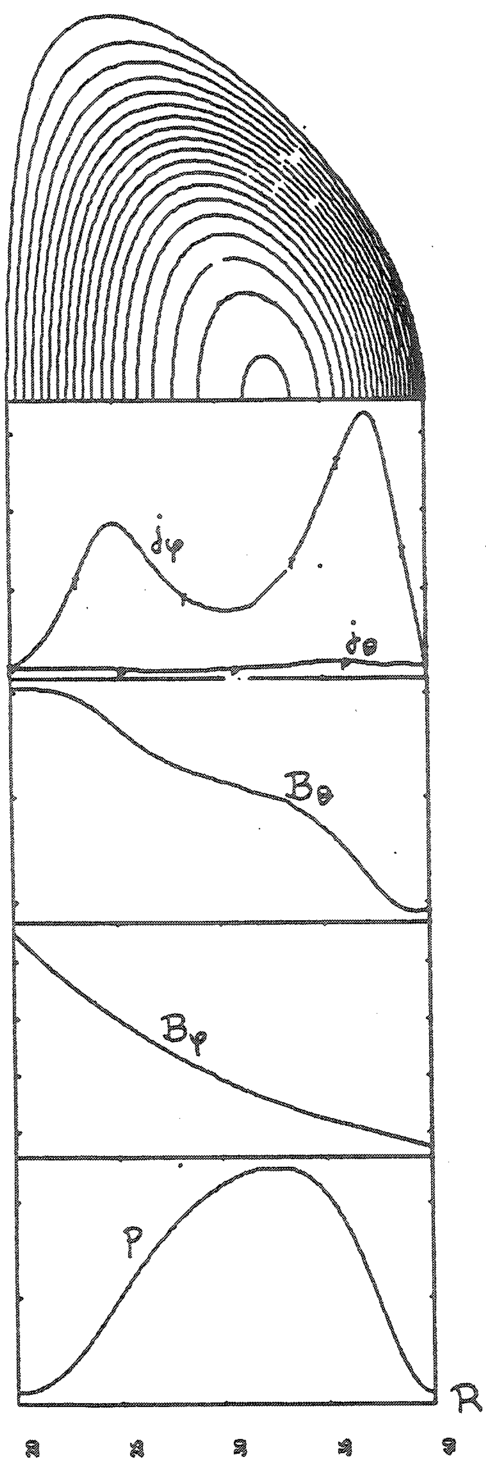
$\beta_N = 3.1$

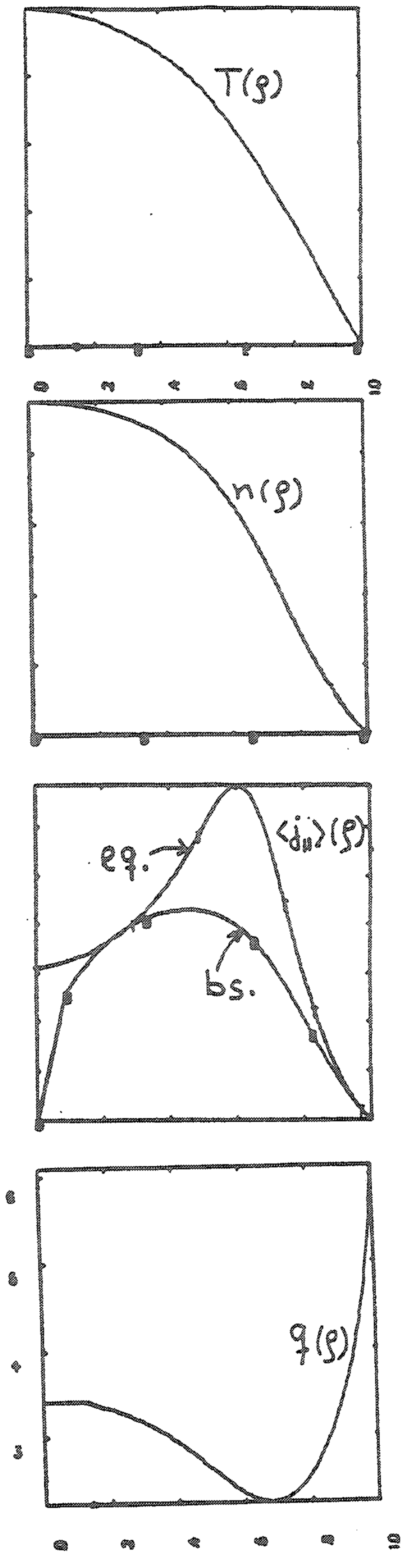
$\beta = 3.4\%$

$p_0/p_{av} = 2.8$

$l_i = 0.77$

$f_{bs} = 0.70$





CURRENT DRIVE SIMULATION FOR "ADVANCED TOKAMAK BURNING EXPERIMENT"

$R_0 = 5.60$ m, $a = 1.75$ m

$B_0 = 6.35$ T, $I = 12.0$ MA

$P_{LH} = 60$ MW @ 5.5 GHz

$P_{NBI} = 20$ MW @ 500 keV peak

FREE BOUNDARY EQUILIBRIUM AND CURRENT DRIVE SIMULATION WITH "ACCOME" CODE.

MHD STABILITY ANALYSIS WITH "KINX" CODE.

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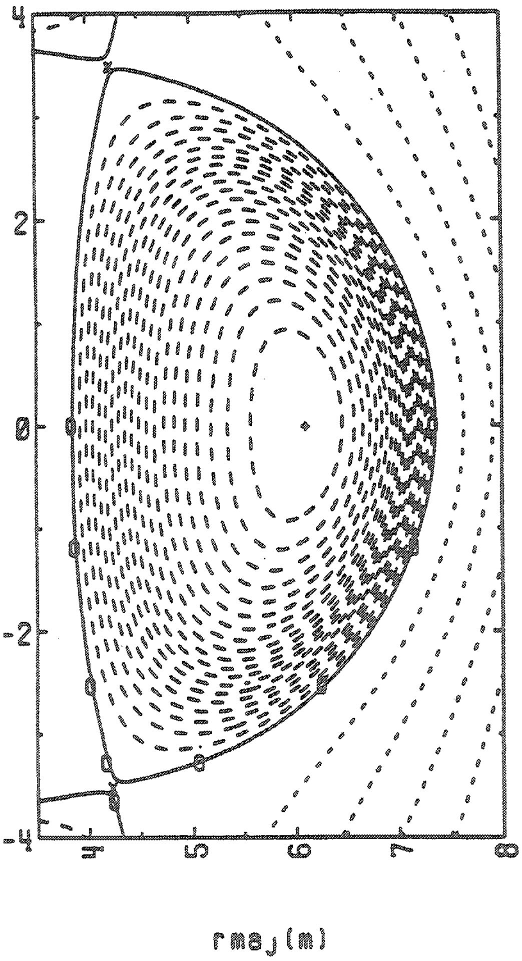
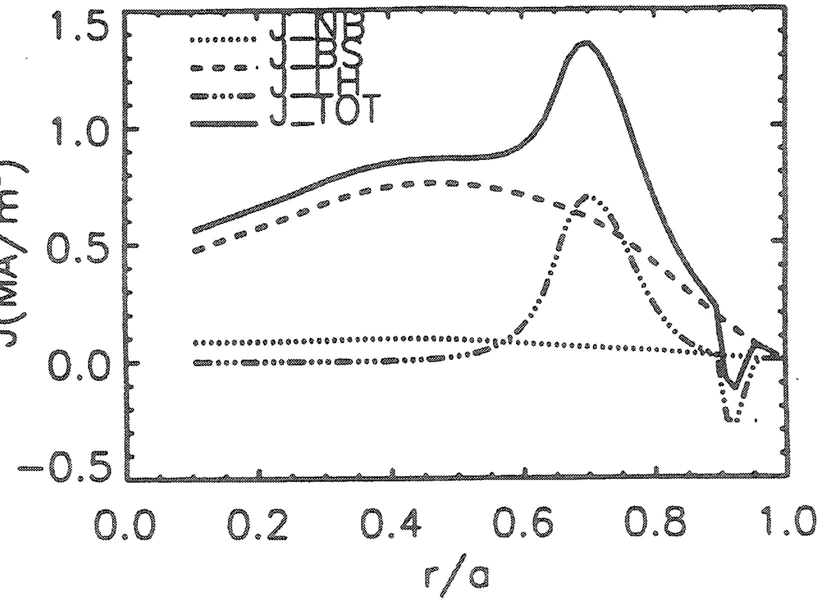
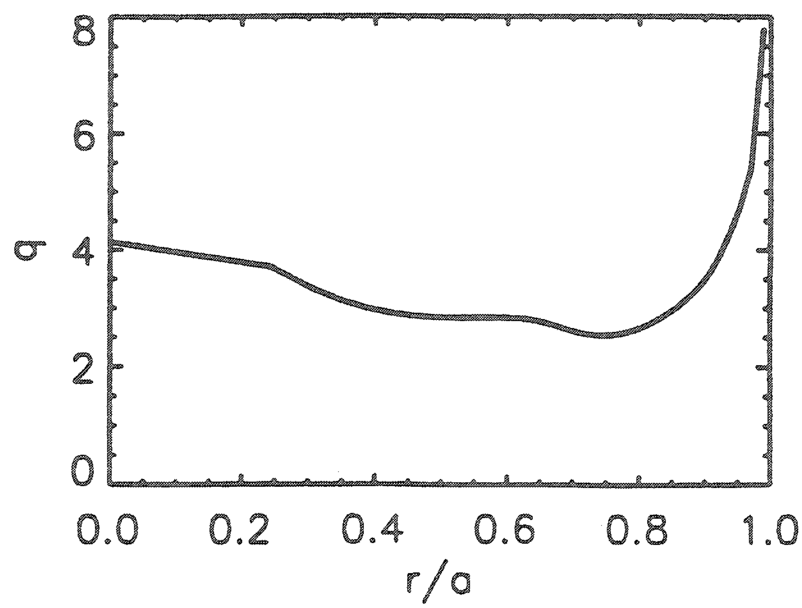
ACCOME REVERSED SHEAR EQUILIBRIUM





Current density profiles



q profile

ACCOME RESULTS OF ATBX REVERSED SHEAR EQUILIBRIUM

$$p(\psi) = n(\psi)T(\psi) = p_o(1-\psi)^2;$$

$$T(\psi) = T_0/[0.70(1-\psi)^{1.5} + 0.30(1-\psi^4)]$$

$n_{e0} = 2.00 \times 10^{20}\mathrm{m}^{-3}$	$\kappa_{95} = 1.85$	$\beta_t = 2.91\%$
$\langle n_e\rangle = 0.983 \times 10^{20}\mathrm{m}^{-3}$	$\delta_{95} = 0.44$	$\beta_p = 1.64$
$T_{e0} = 22.0$ keV	$q_0 = 4.0$	$\beta_N = 2.79$
$\langle T_e\rangle_n = 16.07$ keV	$q_{min} = 2.5$	$I_{NBI} = 0.96$ MA
$T_{d0} = 22.0$ keV	$q_{95} = 5.0$	$I_{LH} = 2.49$ MA
$\langle T_d\rangle_n = 16.07$ keV	$\ell_i = 0.58$	$I_{bs} = 8.53$ MA
$p_0/\langle p\rangle = 2.8$	$I_p = 11.98$ MA	$f_{bs} = I_{bs}/I_p = 0.71$

THIS CONFIGURATION IS STABLE AGAINST ALL IDEAL MHD ($n \neq 0$) MODES WITHOUT ANY CONDUCTING WALL.

ASSUMING $\tau_E = 1.3 \times \tau_{ITER98H} = 2.5 \times \tau_{ITER89L} = 2.0$ s, IT WOULD YIELD 845 MW OF FUSION POWER OR $Q_{DT} = 10.5$.