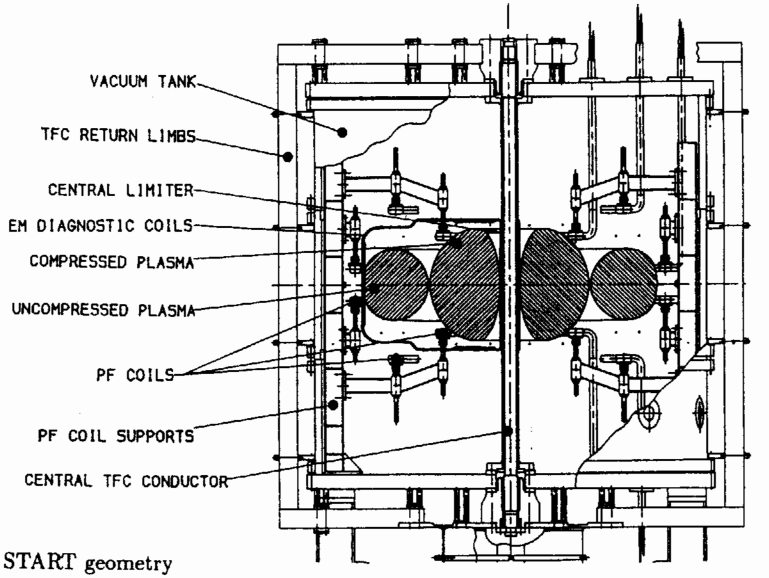

Fig 4. START geometry

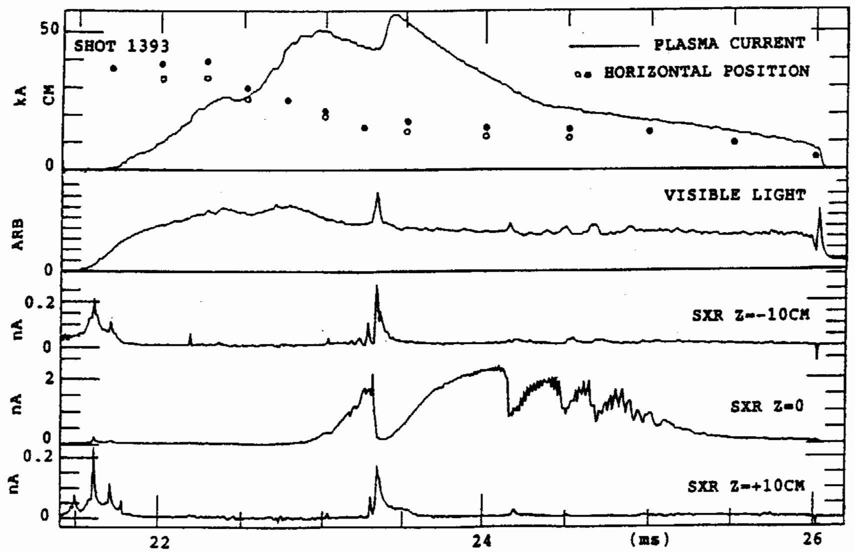

Fig 5. START Results o plasma centre from CCD diagnostic
• plasma centre by equilibrium reconstruction

Confinement Projections for the Burning Plasma Experiment (BPX)

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The mission of the Burning Plasma Experiment (BPX, formerly CIT) is to study the physics of self-heated fusion plasmas (Q = 5 to ignition), and to demonstrate the production of substantial amounts of fusion power (P_{fus} = 100 to 500 MW). Confinement projections for BPX have been made on the basis of 1) dimensional extrapolation, 2) theory-based modeling calibrated to experiment, and 3) statistical scaling from the available empirical data base. The results of all three aproaches, discussed below, roughly coincide. We presently view the third approach, statistical scaling, as the most reliable means for projecting the confinement performance of BPX, and especially for assessing the uncertainty in the projection.

The dimensional scaling approach[1] is based on the observations that the key dimensionless parameters governing tokamak transport behavior are ν^* ($\equiv \nu_{90}/\omega_b$), β, and ρ^* ($\equiv \rho_i/a$), and that all present theories of transport fall close to one of two extreme confinement scalings, Bohm ($\omega_c\tau_E \propto \rho^{*-2}$) or "gyro-Bohm" ($\omega_c\tau_E \propto \rho^{*-3}$) when ν^* and β are held fixed. Thus it is reasonable to assume that plasmas in present devices which achieve values of ν^* and β which are accessible in BPX can be used as bases for Bohm or gyro-Bohm scaling of confinement to BPX conditions, as illustrated in Table 1. [Aspect ratio effects are factored out by using the experimental result[2] that $nT\tau$ depends on I_p and R/a in the combination (I_pR/a)]. The design parameters for BPX are R = 2.59m, a = 0.8m, κ_{95} ~ 2, δ_{95} ~ 0.35, I_p = 10.6MA, B_T = 8.1T, $q_{95} \geq 3.2$, P_{ICRF} = 20 MW. The device and facilities can accommodate upgrades in tokamak power supplies such that I_p = 11.8MA and B_T = 9T can be provided, and in heating power up to 30 MW of ICRF, or 50 MW of ICRF + ECH. Extrapolation based on dimensional scaling gives Q's in the required range, even with the more pessimistic Bohm scaling, at plasma currents below the nominal 10.6MA operating point. The "starting point" discharges in DIII-D and JET have not been optimized for this purpose. Developing optimal starting point conditions, and discriminating experimentally between Bohm and gyro-Bohm scaling, are two key elements of the BPX Physics R&D Plan[3].

Confinement projections have also been made using simulations based on a Multi-Mode model[4] which includes transport due to trapped electron modes, ion temperature gradient modes, and resistive ballooning modes. This model has been calibrated against experimental data from TFTR, DIII-D, JET, PDX, and ASDEX. A preliminary edge stabilization model to simulate H-mode confinement effects[5] is included. The density profile is simulated in an ad-hoc manner to provide a very flat $n_e(r)$. Q~7 is predicted for I_p = 10.6MA, B_T = 8.1 T. The transport coefficients of the Rebut-Lallia model[6], however, are very optimistic in comparison with the Multi-Mode model, giving both χ_e and χ_i 2 – 3 times lower in the confinement zone (χ_e ~ 0.3 m^2/sec *vs.* 0.8 m^2/sec), and so implying a much greater predicted Q.

TABLE I

	DIII-D	BPX (Bohm – g-B)	JET	BPX (Bohm – g-B)
R (m)	1.7	2.6	3.1	2.6
a (m)	0.62	0.79	1.0	0.79
κ_x	2.1	2.1	1.9	1.9
I_p (MA)	2.0	9.2	4.2	10.0
B_T (T)	2.1	9	2.8	9
T_i/T_e	1.29		1.09	
n_{D0} (x10^{20}/m^3)	1.1	7.0	0.56	2.9
τ_E (sec)	0.21	0.51 – 1.64	1.25	1.24 – 2.23
β	4.1%	4.1%	2.4%	2.4%
ν^*	0.083	0.083	0.027	0.027
ρ^* ratio		0.31		0.56
$P_\alpha + P_{aux}$ (MW)	12	190 – 58	7.2	36 – 21
Q		7 – ∞		25 – ∞

TABLE II

Device	$\tau_E^{dia}/\tau_E^{ITER89-P}$	$\tau_E^{MHD}/\tau_E^{ITER89-P}$
JET	2.10 ± 0.38	1.86 ± 0.35
DIII-D	1.70 ± 0.13	1.70 ± 0.21
ASDEX	2.23 ± 0.22	(2.73 ± 0.30)
PBX-M	–	2.05 ± 0.26
PDX	–	1.56 ± 0.33
JFT-2M	1.51 ± 0.16	1.79 ± 0.21
	1.88 ± 0.34	1.79 ± 0.18 (1.95 ± 0.42 incl. ASDEX)

At present we judge that the most reliable method for projecting the performance of BPX is based on analysis of the recently-developed ITER H-mode database[7]. Table II shows the mean ratio of the H-mode confinement data to the ITER89-P scaling relation for each machine in the database, sorted by data type. The data analyzed is the "standard" dataset defined by the authors (ELM'ing and ELM-free) further constrained by dW/dt < 0.2P_{heat} and q_{95} < 5.0. The ranges in the body of the Table indicate shot-to-shot scatter, while the ranges in the averages indicate machine-to-machine scatter. Constraining to the diamagnetic data where available, in order to minimize systematic uncertainties and fast ion effects, and taking the MHD data for PDX and PBX-M which had perpendicular and mixed parallel and perpendicular injection respectively, one obtains a machine-averaged L-mode enhancement factor of 1.85 ± 0.31 (figure 1).

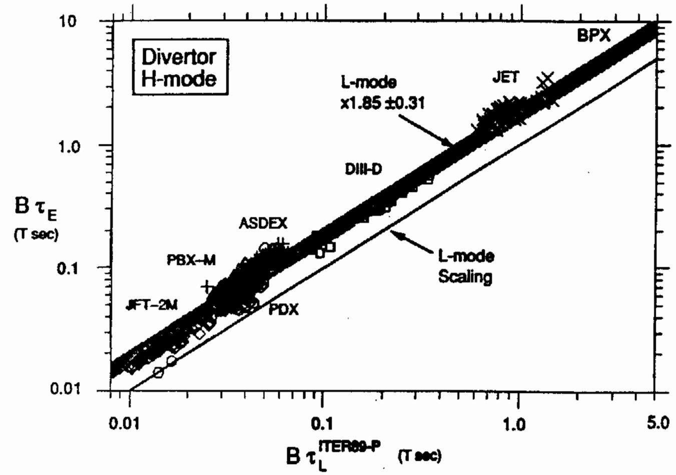

Figure 1. ITER H-mode database for $B\tau_E$ plotted *vs.* ITER89-P L-mode scaling. Data type (MHD *vs.* diamagnetic) selected to minimize fast ion contribution.

Scaling relations have also been developed for H-mode data, but we view these as too preliminary for use as the basis for extrapolation. For typical Q ~ 10 conditions in BPX ($P_{aux} + P_{RF} - P_{brems}$ = 50 MW, $\overline{n_e}$ = 2.5 x 10^{20}/m^3) we project τ_E = 1.85x ITER89-P = 1.01 sec. The DIII-D – JET scaling[8] gives 0.961 sec, the ITER90-H ELM-free scaling gives 1.26 sec, the ITER90-H direct regression fit to the full standard dataset gives 1.90 sec, and the random coefficients model[9] gives 1.25 sec, with an uncertainty of ± 26%. This uncertainty is consistent with a 2-step uncertainty estimate based on combining the 17% uncertainty in the H/L ratio in quadrature with the 17% uncertainty in L-mode extrapolation[10] for machine-averaged performance. Thus we take as the "standard" confinement extrapolation for BPX 1.85x ITER89-P, with an uncertainty of ± 25%. Combining this result with the Monte-Carlo approach to uncertainties[11] in Z_{eff} and $n_e(r)$ gives the projected range in Q shown in figure 2.

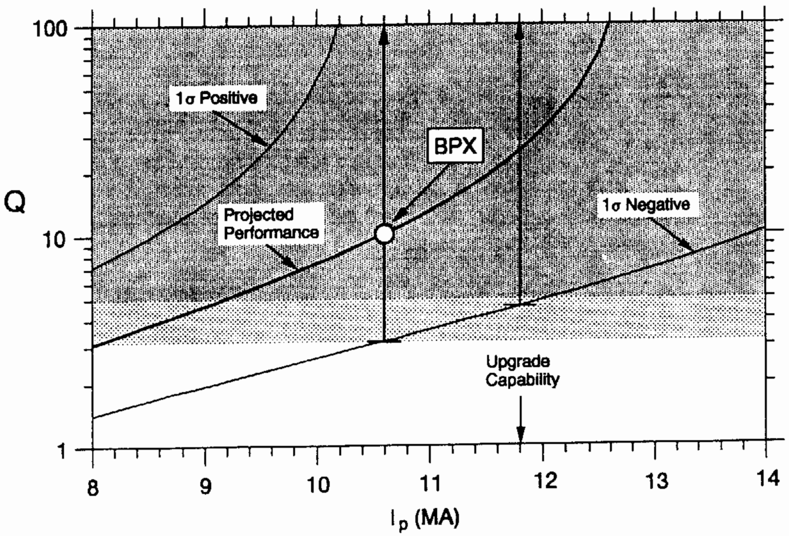

Figure 2. Range of Q projection for BPX *vs.* plasma current at fixed q. Projected peformance for JET at 5MA is Q_{th} = 0.5, and for ITER with 10% helium is Q = 25.

We conclude that the BPX device has adequate performance to achieve its mission of determining the confinement physics, operational limits, and α-particle dynamics of DT plasmas with α power greater than auxiliary heating power, while producing more than 100 MW of fusion power. The upgrade capabilities of the device provide assurance that this mission can be achieved even in the case of unfavorable plasma performance.

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ISOTOPE DEPENDENCE OF ELECTRON PARTICLE TRANSPORT IN ASDEX

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Introduction

The isotope dependence of electron particle transport in the ASDEX bulk plasma was investigated using gas oscillation techniques /1/. Ohmic discharges in hydrogen and deuterium were evaluated for densities up to the density limit, and some experiments were carried out in helium. In addition, neutral beam heated L-type plasmas at ohmic target densities corresponding to saturated confinement could be analyzed by this method for both hydrogen isotopes.

Method

Small density perturbations about equilibrium, induced by sinusoidal modulation of the gas valve, were analyzed for the different channels of the ASDEX HCN-laser-interferometer. The measured pattern of amplitudes and phase shifts is compared to solutions of the particle conservation equation, $\partial n/\partial t = -\nabla \cdot \Gamma + P$. A transport law with a diffusive and a convective flux component $\Gamma = -D\,\nabla n - Vn$ is assumed. The coefficients D(r) and V(r) are determined with a crude radial resolution, using a spatial transport model with constant inner and peripheral values of D and V/r and a linear interpolation in between. The physical justification for this model, which seems adequate to the limited number of experimental chords, is that the central and outer plasma regions normally have greatly different parameters and often different transport characteristics.The absolute numbers of D and V for each plasma zone are gained from a numerical fitting procedure.

Results for ohmic plasmas

Using the gas oscillation technique, density scans including the range of linear ohmic confinement (LOC), where the energy confinement time τ_E linearly increases with density, to saturated ohmic confinement (SOC) were performed for standard values of plasma current and main field (320 kA / 2.17 T) and standard wall conditions (stainless steel or carbonized). A clear isotope effect in both diffusion D and inward convection V was found in all plasma regions, except for V