CONF-810680--1

PHYSICS ISSUES OF AN EBT REACTOR*

N. A. Uckan and EBT Theory Group†
Oak Ridge National Laboratory
Oak Ridge, Tennessee, U.S.A.

*Research sponsored by the Office of Fusion Energy, U. S. Department of Energy, under contracy W-7405-eng-26 with the Union Carbide Corporation.

†D. B. Batchelor, L. A. Berry, M. R. Gordinier, C. L. Hedrick, E. F. Jaeger, L. W. Owen, and D. A. Spong.

PHYSICS ISSUES OF AN EBT REACTOR

N. A. Uckan and EBT Theory Group
Oak Ridge National Laboratory
Oak Ridge, Tennessee, U.S.A.

ABSTRACT

The ELMO Bumpy Torus (EBT) concept provides a unique basis for a steady-state fusion reactor in a favorable geometry, and it has the potential for a high power density with a significant Q value. The similarity of the dimensionless parameters of the present experiments to a reactor grade plasma and observed confinement characteristics indicates plausible extrapolations and projections for a reactor; however, there are a number of physics (as well as technology) issues to be resolved. There are difficulties in extrapolating results of simplified (and/or untested) theoretical models to an actual closely coupled, hybrid (toroidal core, hot electron ring, surface plasma, etc.) geometry. There are also uncertainties in extrapolating experimental results from low density, low temperature (low beta) plasmas to predict the behavior of a burning plasma.

Basically, the plasma physics areas that influence the operating characteristics of EBTs are the following: (1) particle orbits, equilibrium, and magnetic; (2) stability boundaries of both core and ring plasmas; (3) transport scaling; (4) heating; and (5) ring-core interaction and power balance. In addition to the "conventional" mode of EBT operation, innovative ideas that enhance the reactor performance include: (a) the use of supplementary (and/or trim) coils to improve confinement (and/or stability); (b) control of ambipolar potential (and its sign, i.e., positive electric field) to enhance confinement (and to be able to burn alternative fuels, i.e., D-D, etc., in a reasonably sized reactor); and (c) the possibility of "fundamental ring" mode heating to reduce microwave frequency requirements by a factor of 2. This paper reviews each of these areas briefly and discusses their projections to a reactor.

1. INTRODUCTION

The ELMO Bumpy Torus (EBT) concept combines many of the desirable features of both tokamaks and mirrors into an attractive reactor configuration. Bumpy torus plasmas employing electron cyclotron heating (ECH) are currently being studied in EBT [1-3] at the Oak Ridge National Laboratory (ORNL) and in the Nagoya Bumpy Torus (NBT) [4] at the Institute of Plasma Physics, Nagoya University.

The key element of EBT is the high beta, hot electron ring (annulus) formed in the midplane of each mirror section by microwave heating. The local magnetic wells produced by these annuli stabilize the toroidally confined plasma [5] (in an average "minimum-B" stabilization). Both the theoretical studies [5] and the experiments [1-4] have demonstrated the existence of a macroscopically stable plasma confinement regime. The observed confinement properties of the core [1-4] and ring [6] plasma agree well with the classical and neoclassical theoretical losses [7-11].

Although achieved plasma parameters in the present EBT and NBT experiments have been modest, the experiments, with the exception of toroidal core beta, have been operating in the dimensionless parameters regime remarkedly close to a reactor [3, 12] with an observed [1-4] collisionless scaling of $n\tau \sim T^{3/2}$. This favorable scaling of $n\tau$ (coupled with the constancy of most of the dimensionless parameters) gives promising reactor projections.

Many years of steady progress in EBT research, as well as in its reactor potential, have led to plans for constructing the EBT Proof-of-Principle (EBT-P) experiment [13], which is a large-scale EBT. The task involved with EBT-P [13, 14] will be to study confinement scaling, power balance, and stability boundaries of both core and ring plasmas, while raising the important physical quantities (n, T, τ, etc.) to a level that could test whether the EBT concept has the capability to lead to a viable D-T burning device.

2. CHARACTERISTICS OF EBT PLASMA

In electron cyclotron heated bumpy tori (EBT and NBT), the two principal plasma components are high beta, hot electron rings and warm toroidal core plasma. While the hot electron rings provide the minimum-B that is necessary to stabilize the toroidal core plasma [5], cooler electrons (provided by the toroidal core plasma) are required for the stability [6, 15] of the rings. The ring beta ($\beta_{ring} \sim 5$-15%), at which the quiescent mode of operation was achieved [1], agrees with the theoretical estimates of the beta value required to produce a local minimum in the magnetic field [5]. The confinement properties [1-4] in this mode are consistent with the neoclassical theoretical predictions [8, 9] (i.e., confinement time increases with electron temperature).

The hot electron rings form at the location of the second harmonic ($\omega \sim 2\omega_{ce}$) resonance with a radial width δ_R of a few hot electron gyroradii ρ_{eR} and an axial length $\ell_R \lesssim$ plasma radius a [6]. Electrostatic potential well forms in the quiescent mode, and the rim of the potential well is located in the region of the rings and defines the radius of the stable core plasma. The electric field is radially inward inside the ring and outward outside the ring. Improvements in plasma parameters (both ring and core) and confinement were observed with an increase in microwave power and frequency (or resonant magnetic field, $f_\mu \sim B_{res}$).

The EBTs are closed field line devices and necessitate a magnetic field symmetry for particle confinement. The field error in the system can cause enhanced fluctuations, increased particle diffusion, deterioration of plasma parameters, etc., if it exceeds a critical value of $(\Delta B/B)_{cr} \sim \rho/L$, where ρ and L are the particle gyroradius and effective scale length ($\sim$ magnetic field radius of curvature) of the torus, respectively [16, 17]. This value is about 10^{-3} in the present EBT (the design value of EBT-I/S is 10^{-4}). In the experiments, the optimization of plasma parameters occurs when magnetic error fields are globally cancelled (by superimposed, weak, quadrupole magnetic fields).

Collisionless scaling ($\nu/\Omega < 1$, where ν is the collision frequency and Ω is the poloidal precessional drift frequency) has been observed in experiments where the electron energy confinement time increases with temperature ($\tau_E \sim T_e^{3/2}$). The detailed theoretical calculations [8-10] compare favorably with experimental results and confirm that the gross behavior of the toroidal core density and temperatures is dominated by the neoclassical electron transport coefficients [7] (while ion transport determines the electric field to maintain ambipolarity [8-10]). This leads to EBT scaling of [2, 3]

$$n\tau \sim A^2 T_e^{3/2}\left(1 + \frac{R_B}{R_E}\frac{e\phi}{T_e}\right) \quad \text{for} \quad \nu/\Omega < 1, \tag{1}$$

where $\nu/\Omega \sim nBR_B a/T_e^{5/2}$; a is the mean plasma radius; A is the magnetic aspect ratio defined as R/R_B; and R, R_B, and R_E are the major radius of the torus, the magnetic radius of curvature, and the electric field scale length, respectively. The potential $e\phi$ is approximately proportional to the ion temperature T_i. Equation (1) can be modified by several improvements that include: (1) operation at a lower collisionality due to better control of plasma (for example, separate control of core and ring heating); (2) direct ion heating leading to larger potential well and better confinement; (3) modification of aspect ratio by aspect ratio enhancement (ARE) or symmetrizing [18] (SYM) coils (the effective aspect ratio $A_{eff} = Af_A$ with an aspect ratio enhancement factor $f_A \sim 1.5$-2.0), leading to better single particle orbits and to better confinement; and (4) operation at higher frequencies (magnetic fields).

The existence of stable equilibria for the hot electron rings and the ability to sustain them with acceptably low amounts of microwave power are central to the successful operation of EBTs (and to the viability of the EBT reactor concept). The high beta ring is shown to provide a minimum-B equilibrium, which produces a localized magnetic well and increased magnetic gradients in the vicinity of the ring. The dominant ring losses are drag cooling, scattering, and synchrotron radiation [6, 19]. In EBT-I and EBT-S, this power is modest (∿5-10 kW) and is reasonably well estimated by the theoretical models [6, 11, 19]. Studies [6] indicate that the following parameters are important for the ring power loss $P_{\mu R}$: ring beta β_R; ratio of cold to hot plasma density f_R required for ring stability [15]; magnetic field at the ring location B_R; fraction of microwave cutoff f_c; and ring volume V_R. Experiments in EBTs (and NBT), as well as early ECH mirror experiments, indicate that the ring energies are probably limited by adiabaticity [6, 11] and $\rho_{eR}/R_B \sim 5\text{-}6 \times 10^{-2}$.

A comparison of the observed ring and core plasma parameters in past (ELMO and simple mirrors for the ring properties) and present (EBT-I, EBT-S, and NBT for both ring and core) experiments suggests that most of the dimensionless parameters are constant [3, 6, 11, 12]. When the dimensionless parameters required for an EBT reactor, as well as for EBT-P, are examined one finds that with the exception of core beta, the EBT-I/S experiments are already operating in the correct regimes [3]. The dimensionless parameters that are known to influence stability, transport, and ring scaling are listed in Table I for EBT-I/S, along with those projected for EBT-P and a reactor.

3. PHYSICS ISSUES

3.1 Equilibrium, particle orbits, and magnetics

In EBT most of the drift orbits of toroidally passing ($V_\parallel \approx V$) and mirror trapped ($V_\parallel \approx 0$) particles are nearly concentric circles shifted inward from the minor axis toward the major axis of the torus. This shift of drift orbits, which scales as 1/A (where A is the magnetic aspect ratio), plays a major role in diffusive and direct particle losses. For toroidal core plasma the dominant loss mechanism is diffusion [3, 8-10] (thus $n\tau \sim A^2T_e^{3/2}$), whereas the direct particle losses are the dominant mechanism for high energy ring electrons and alpha particles. Increasing the aspect ratio reduces the drift orbit shift and improves the confinement of all classes of particles. There are ways to modify the vacuum magnetic field in order to decrease the dispersion in the drift orbits without increasing the physical size of the device. These are generically called "aspect ratio enhancement" methods that include magnetic configurations [18] such as ARE and SYM coils. The use of SYM coils offers the most promise of good plasma performance in reactors that are smaller (by up to 50%) than reactors that do not employ supplementary coils [18].

The spatial position of hot electron rings is critical to efficient utilization of the magnetic volume within the vacuum chamber. [Rings form near contours of constant $|B_{vacuum}|$ in the midplane at the location of the second harmonic resonance $\omega \approx 2\,\omega_{ce}$.] The three-dimensional (3-D) tensor pressure equilibrium calculations in a reactor indicate that the maximum radius of the hot electron rings (as well as the core plasma) can be nearly doubled by the effect of field symmetrization (by SYM coils [18]).

3.2 Stability

The stability requirements of hot electron rings and the toroidal core plasma are closely coupled, and their interaction defines stable operating regimes for the toroidal core and ring plasmas and predicts β_{core} limits [6, 20, 21]. An EBT reactor requires the stable confinement of a toroidal plasma with an average beta, $\langle\beta_{core}\rangle$, in the range of ∿10-15%. Because of the simultaneous importance of the kinetic, finite geometry, and profile effects, the general problem of ring-core stability is complex and has been examined only with simplified models.

Both magnetohydrodynamic (MHD) [5] models (derived from modified energy principle) and kinetic models in slab geometry [20, 21] show that the core plasma is stabilized only if the ring beta exceeds the critical value required to produce a distinct local minimum in B (β_{crit} ∿ ring radial thickness/mean radius of curvature ∿ 10-15%). At higher values of ring beta, the earlier decoupled MHD calculations [5] indicated stable core betas to be as high as the ring beta ($\beta_{core} \lesssim \beta_{crit}$ ∿ 30-40%). Coupled ring-core kinetic calculations [20, 21], on the other hand, indicate a saturation in core beta to values near $0(\beta_{crit})$. The details of beta limits and their implications for a reactor are discussed in Ref. [22].

3.3 Transport scaling

Plasma confinement in EBT depends on the modifications of the toroidal vertical drift by the poloidal ∇B and ExB drifts (produced by bumpiness in the toroidal field and by the ambipolar electric field). Theory and experimental observations of EBT plasmas suggest that there is a macroscopically stable regime of operation (quiescent mode) in which the radial plasma losses are dominated by neoclassical collisional processes.

The displacement of drift orbits $\Delta x = v_y/\Omega$ acts as a basic step size for diffusion of particles and energy, where $v_y \sim T/eBR$ is the toroidal drift velocity and $\Omega \sim T/(eBR_B r)(1 + eE_r R_B/T)$ is the poloidal precessional drift frequency; $E_r (\sim \phi/R_E)$ is the radial electric field. For the experimentally observed sign of the electric field [2], radially pointing inward, $eE_r R_B$ is negative for ions and positive for electrons, thus causing $\Omega \approx 0$ for a class of ions. In the collisionless limit ($\nu_e/\Omega_e < 1$, as in the experiments), the diffusion coefficient for electrons (for negative electric fields) is given by [7]

$$D_e \sim \langle \nu_e (\Delta x)^2 \rangle \tag{2}$$

and

$$D_e \sim \frac{a^2}{\left[A_{eff}^2 \; T_e^{3/2} \left(1 + \frac{eE_r R_B}{T_e}\right)\right]} , \tag{3}$$

which basically leads to EBT scaling, given in Eq. (1).

In order that electron and ion fluxes balance locally, a self-consistent, radial electric field must build up to establish ambipolar particle transport. Transport coefficients for ions (with negative electric field) exhibit collisional [7] ($\nu/\Omega_o > 1$), plateau [23] ($\varepsilon^{3/2} < \nu/\Omega_o < 1$), and banana [10, 24] ($\nu/\Omega_o < \varepsilon^{3/2}$) transport regimes ($\nu$ = collision frequency, Ω_o = poloidal ∇B drift frequency, $\varepsilon = a/R$ inverse aspect ratio). The plateau regime [23], where D_i is independent of ν, is believed to be more relevant to past, present, and near-term experiments, and the results of one-dimensional (1-D) (or 1½-D) transport calculations are in good agreement with the experimental observations [8, 10].

The extrapolation of this transport scaling model, which explains the present experiments, to reactor conditions is presently uncertain. These uncertainties include the influence of alpha particle containment on ambipolar electric fields, details of plasma-wall interaction, and ring-core coupling.

The 1-D (or 1½-D) transport calculations show thermally stable, steady-state solutions [8, 9] with the negative electric field (as is observed in the experiments). The same calculations also indicate the possibility of positive electric field solutions, in which case the roles of electrons and ions are interchanged. The equilibrium with positive electric fields would enhance plasma confinement due to scaling of confinement with ion collision frequency instead of electron collision frequency. This possibility makes it possible for EBTs to burn alternative fuels (D-D) in a reasonably sized reactor. The near-term experiments (EBT-P) are expected to explore the possibility of methods for controlling the sign of electric field and ambipolar potential [14].

3.4 Heating

Electron cyclotron heating, neutral beams, ion cyclotron heating (ICH), etc., are all possible candidates for heating of an EBT reactor plasma. The use of ICH for direct ion heating and for controlling the ion distribution offers a number of advantages over neutral beam injection [13, 14]. A pure ICH or neutral beam (or a combination of each with ECH) heated EBT core plasma may, however, have a different thermal stability and transport properties than a plasma heated by ECH only. This is currently under investigation, theoretically; ICH experiments are presently tested on EBT-S.

For an ignited reactor, the core heating would be turned off after ignition; however, the ring ECH power would have to be sustained throughout the steady-state operation. It is desirable to have a separate heating source for the core and ring plasmas, not only for independent control over the core-ring heating ratio, but also to control the possible stable operating regime of β_{core} and β_{ring} through independent tailoring of the density and temperature profiles. The possibility exists of establishing hot electron rings by fundamental resonance heating at the ring location rather than second harmonic heating. The experiments on EBT-S and NBT are presently under way to test this "fundamental ring" mode operation. If successful, this would reduce microwave frequency requirements by a factor of 2, and the EBT reactor could use the 60-GHz tubes developed for EBT-P (at higher power levels, of course).

3.5 Ring power losses and scaling

Good agreement between the experimental measurements and the theoretical estimates of ring power losses for past (ELMO) and present (EBT-I/S and NBT) experiments provides the same level of confidence in the identified energy loss processes (drag, scattering, and radiation) and in the estimates of energy loss as a function of ring and toroidal plasma parameters [6]. For ring temperatures characteristic of present and near-term EBTs ($T_R \lesssim 1.5$ MeV), drag losses dominate and ring energies are limited by the nonadiabatic particle behavior; ECH experiments conducted over a two decade period [6] obey the $\rho_{eR}/R_B \sim 5\text{-}6 \times 10^{-2}$ scaling. However, in a reactor plasma the ring temperature ($T_R \gtrsim 2$ MeV) is expected to be in radiation (synchrotron) dominated regime, and ring energies will be limited by radiation cooling. The microwave power required to sustain the rings, $P_{\mu R}$, can be approximated (in mks units) to be

$$\frac{P_{\mu R}}{V_R}\ (\mathrm{MW/m^3}) \approx 0.16\beta_R B_R^4 \left[1 + 0.5(\gamma - 1) + 15\ f_c \frac{\gamma/\gamma - 1}{\sqrt{\gamma^2 - 1}}\right]$$

$$\approx 1.2 \frac{1}{f_R} \frac{\beta_*^2 B_R^4}{(T_*/511)^2} \left\{\frac{\gamma}{\sqrt{\gamma^2 - 1}} + 0.06 \frac{T_*/511}{\beta_*} (\gamma^2 - 1)\right\}, \quad (4)$$

where $\beta_*(\sim n_*T_*/B_R^2)$ is the toroidal core plasma beta near the vicinity of the ring, which enters into the stability calculations, and T_* is the core plasma temperature near the ring location (other quantities are defined earlier). Defining a reactor Q value that is roughly the ratio of the fusion power produced ($P_{th} \sim \beta^2B^4$) to the ring sustaining power and taking into account the appropriate conversion efficiencies (i.e., thermal-to-electric conversion and microwave coupling), the overall reactor Q_E ($Q_{electric}$) value can be given as [11, 22]

$$Q_E \approx 7.7 \times 10^{17} \cdot f_R \cdot \frac{V_P}{V_R} \cdot \langle\sigma v\rangle_{DT} \cdot \left(\frac{T_*}{T}\right)^2 \frac{\beta^2B^4}{\beta_*^2B_R^4} \frac{1}{\{G(\gamma,*)\}}$$

$$\approx 4 \times 10^{18} \cdot f_R \cdot \frac{1}{\varepsilon} \cdot \langle\sigma v\rangle_{DT} \cdot \kappa^2 \cdot \{G(\gamma,*)\}^{-1} \quad . \qquad (5)$$

where V_p is the toroidal plasma volume, $G(\gamma,*)$ is the quantity in curly brackets given in Eq. (4), $\kappa = n/n_* \approx T/T_*$ is the profile factor, and $\varepsilon = \delta_R/R_B$ (ring thickness/radius of curvature), which is one of the key parameters that enters in the determination of limits on β_* (core plasma is stable if $\beta_* \lesssim \alpha\varepsilon$ with the numerical factor $\alpha \sim 2$-4). As pointed out earlier, the stability of hot electron rings requires an appreciable cold electron density component near the vicinity of the rings (i.e., $f_R \gg 1$). In a reactor plasma, $f_R \sim O(10^1 - 10^2)$ which leads to Q_E values ranging from as low as a few ($\sim$2-5) to $\sim$50 depending on the uncertainties in ring scale lengths and β_* limits [22]. There is a close coupling, which should be considered simultaneously, between ring thickness, toroidal core plasma/ring stability, transport properties, and power losses.

REFERENCES

[1] DANDL, R. A., et al., The ELMO Bumpy Torus Experiment, Oak Ridge National Laboratory Rep. ORNL/TM-3694 (1971); DANDL, R. A., et al., Plasma Physics and Controlled Nuclear Fusion Research 1974, Vol. 2 (1975) 141.

[2] DANDL, R. A., et al., Plasma Physics and Controlled Nuclear Fusion Research 1978, Vol. 2 (1979) 365.

[3] BERRY, L. A., HEDRICK, C. L., UCKAN, N. A., ELMO Bumpy Torus, Oak Ridge National Laboratory Rep. ORNL/TM-6743 (1979).

[4] FUJIWARA, M., et al., BAITY, F. W., et al., Experimental studies of plasma confinement in the bumpy torus, to be published in Plasma Physics and Controlled Nuclear Fusion Research 1980, IAEA, Vienna.

[5] NELSON, D. B., HEDRICK, C. L., Nucl. Fusion 19 (1979) 283; GUEST, G. E., HEDRICK, C. L., NELSON, D. B., Phys. Fluids 18 (1975) 871.

[6] UCKAN, N. A., Ed., EBT Ring Physics: Proc. of the Workshop, Oak Ridge National Laboratory CONF-791228, (1979).
[7] KOVRIZHNYKH, L. M., Sov. Phys. JETP 29 (1969) 475; SPONG, D.A., HARRIS, E. G., HEDRICK, C. L., Nucl. Fusion 19 (1979) 665.
[8] JAEGER, E. F., et al., Nucl. Fusion 19 (1979) 1627.
[9] JAEGER, E. F., HEDRICK, C. L., ARD, W. B., Phys. Rev. Lett. 43 (1979) 855.
[10] CATTO, P. J., et al., EBT transport, heating and stability, to be published in Plasma Physics and Controlled Nuclear Fusion Research 1980, IAEA, Vienna.
[11] UCKAN, N. A., et al., Physics of hot electron rings in EBT: theory and experiment, to be published in Plasma Physics and Controlled Nuclear Fusion Research 1980, IAEA, Vienna.
[12] UCKAN, N. A., et al., Plasma Physics and Controlled Nuclear Fusion Research 1978, Vol. 2 (1979) 343; UCKAN, N. A., Overview of EBT reactor projections, to be published in Nucl. Engineering Design.
[13] EBT-P Proposed Reference Design Report, Oak Ridge National Laboratory Rep. ORNL/TM-7191 (1980).
[14] ARD, W. B., KASHUBA, R. J., EBT-P the proof of principle experiment for the EBT reactor concept (in this proceedings).
[15] DOMINGUEZ, R. R., BERK, H. L., Phys. Fluids 21 (1978) 827.
[16] QUON, B. H., et al., Effects of Global Field Errors on ELMO Bumpy Torus, Oak Ridge National Laboratory Rep. ORNL/TM-6075 (1977).
[17] UCKAN, T., et al., Field errors in EBT and their effects on ambipolar potential, CALLEN, J. D., Magnetic field error effects on ambipolar potential, to be published in Proc. Ambipolar Potential Formation and Control, CONF-810511.
[18] OWEN, L. W., UCKAN, N. A., EBT reactor magnetics and particle confinement, to be published in J. Fusion Energy.
[19] BOROWSKI, S. K., UCKAN, N. A., JAEGER, E. F., KAMMASH, T., Nucl. Fusion 20 (1980) 177.
[20] VAN DAM, J. W., LEE, Y. C., Stability analysis of a hot electron EBT plasma, in EBT Ring Physics: Proc. of the Workshop, UCKAN, N. A., Ed., Oak Ridge National Laboratory CONF-791228, pp. 471-489 (1980).
[21] NELSON, D. B., Phys. Fluids 23 (1980) 1850.
[22] UCKAN, N. A., SPONG, D. A., NELSON, D. B., Beta Limits in EBT and their Implications for a Reactor (in this proceedings).
[23] SPONG, D. A., HEDRICK, C. L., Phys. Fluids 23 (1980) 1903.
[24] HAZELTINE, R. D., et al., Nucl. Fusion 19 (1979) 1597.

Table I. Dimensionless parameters

	EBT-I/S	EBT-P	EBT-R	Critical value (if any)	
ρ_e/a	$\sim 10^{-3}$	$\sim 4 \times 10^{-4}$	$\sim 10^{-4}$		
ρ_i/a	$\sim 2 \times 10^{-2}$	$\lesssim 10^{-2}$	4×10^{-3}		Same or in the direction of increased stability and/or improved confinement
T_e/T_i	5-3	4-1	~ 1		
ω_{pe}/ω_{ce}	<0.7	~ 0.7	$\gtrsim 0.8$		
A	~ 10	~ 15	$\gtrsim 15$	~ 10	
$e\phi/kT$	~ 1	~ 1 (?)	~ 1 (?)		
β_{ring}	0.1-0.3	0.2-0.4	0.2-0.5	$>\beta_{crit} \sim 10\%$	
ω_{*e}/ω_{ci}	>1	~ 0.8-0.2	~ 0.1	?	
n_{cold}/n_{hot}	~ 3-5	~ 5-10	>10	?	Ring scaling — EBT-P will provide better understanding
δ_R/a	0.1-0.2	~ 0.9 (?)	~ 0.1 (?)	>few ρ_{eR}/a	
ρ_{eR}/R_B	$5\text{-}6 \times 10^{-2}$	$5\text{-}6 \times 10^{-2}$	?	?	
V_R/V_p	$\gtrsim 0.1$	~ 0.1	~ 0.02	<<1	
$(\nu/\Omega)_e$	~ 0.3	~ 0.2	~ 0.2-0.5	<1	Same or improved confinement — EBT-P will provide better understanding
$(\nu/\Omega)_i$	~ 0.4	$\gtrsim 0.05$	$\lesssim 0.01$	<1	
β_{core}(average)	0.001	0.02	0.10		Change appreciably