SOME PHYSICS CONSIDERATIONS FOR TEPR DESIGNS*

J. T. Hogan, J. A. Rome, D. G. McAlees†, S. E. Attenberger

Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

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Summary

A simplified version of the Oak Ridge Tokamak Transport Code is used to assess the implications of confinement scaling, impurity trapping of neutral beam particles and plasma currents driven by neutral injection. The ORNL, ANL and GAC experimental power reactor reference designs are considered.

Introduction

Success in producing plasmas with long energy confinement times in the next generation of tokamaks will stimulate planning for an Experimental Power Reactor: a device which might produce an amount of power by fusion roughly equal to the power needed for plant operation. At present three groups have developed working reference designs: the Oak Ridge National Laboratory,[1] Argonne National Laboratory,[2] and the General Atomic Company.[3] This paper addresses some areas currently under study to assess their impact on EPR designs. The areas are: confinement scaling, the enhanced trapping of neutral beams by impurities, and the sustenance of plasma current by neutral beam injection.

The confinement scaling of reactor devices is unknown and is being tested in injection experiments on ORMAK, and in the ohmically heated PLT and T10 devices. A recent survey of theoretical predictions[4] has been used for EPR designs, and we apply a slightly different test, based on plasma collisionality, $\nu^*_{e,i}$, to compare the three-reference designs on a common basis. We use a simplified version of the Oak Ridge Tokamak Transport Code[5] to calculate the energy balance.

Intense neutral beams are seen as an important heating mechanism in each EPR design. While the usual criterion for beam trapping is the impact of neutral deuterons on the plasma ions, there has been concern over the effects of trapping by impurity ions. This enhanced trapping increases the energies needed or alternatively, may force adoption of perpendicular injection of the beam.

Ohkawa[6] has suggested the possibility of a steady-state tokamak in which the rotational transform is supplied by a beam-induced current. Recent calculations[7] have improved our estimates of the available beam current, and we calculate the injected beam currents required.

Confinement Scaling

To compare the energy balance and confinement scaling in EPR designs we adopt a simplified version of the model used to describe present experiments, and add the thermonuclear terms of interest. The model treats the plasma densities as prescribed functions of space and time. The correct simulation requires the full treatment of neutral gas and fast ions (Fokker-Planck or moments) and these take substantially different forms for large plasmas with appreciable populations of alpha particles. The fuel is assumed to be a single D-T specie, with atomic mass between 2 and 3 depending on the precise composition. The energy balance equations are:

$$\frac{3}{2}\frac{\partial}{\partial t}[N_e T_e(r,t)] = \frac{1}{r}\frac{\partial}{\partial r}\left[rN_e\chi_e\frac{\partial T_e}{\partial r}\right] + E\cdot j + Q^e_{injection} + Q^e_{Alphas} - C_{LR}n_e n_Z f(T_e) - 3\frac{m_e}{m_f}\frac{T_e - T_f}{\tau_e} \quad (1)$$

$$\frac{3}{2}\frac{\partial}{\partial t}[N_f T_f(r,t)] = \frac{1}{r}\left(rN_i\chi_i\frac{\partial T_f}{\partial r}\right. + 3\frac{m_e}{m_f}\frac{T_e - T_f}{\tau_e} + Q^f_{injection} + Q^f_{Alphas} \quad (2)$$

The electromagnetic field is described by

$$\frac{\partial B_{Pol}}{\partial t}(r,t) = \frac{\partial E_Z}{\partial r};\ E = \eta(j - j_B);\ \mu_0 j = \frac{1}{r}\frac{\partial}{\partial r}(rB_{Pol}) \quad (3)$$

where:

- $N_{e,f}$: electron, fuel densities
- $T_{e,f}$: electron, fuel temperatures
- E, B_{Pol}, j_Z: electric field, poloidal magnetic field, toroidal current density
- j_B: beam-induced current density
- $f(T_e)$: $0.4 + 4.6\, e^{-T_e^2(\mathrm{keV})}$: temperature dependence of line-radiation loss for iron
- $m_{e,f}$: masses of electrons, fuel ions

To represent the plasma transport scaling in the collisionless regime we adopt a model for $\chi_{e,i}$:

$$\chi_e = \chi_{Pseudo\text{-}classical}\cdot\left[1 + \frac{0.16}{\nu_e^{*2}}\right]$$

$$\chi_i = \chi_{Neoclassical}\cdot\left[1 + .01/\nu_e^{*2}\right]$$

This depicts unfavorable scaling beginning at a threshold $\nu^*_e \sim 0.4$, $\nu^*_i \sim 0.1$, roughly as predicted by theory.

Using parameters of the reference designs at ORNL, ANL and GAC, we have obtained the resulting plasma parameters for the same model assumptions. These are -

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†Exxon Nuclear Company, Inc.

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