OAK RIDGE EPR REFERENCE DESIGN

M. Roberts

for the Oak Ridge EPR Project Team

Oak Ridge National Laboratory*
Oak Ridge, Tennessee 37830

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Conf-751125--60

Abstract

A Tokamak EPR reference design is presented as a basis for further study leading to a conceptual design. The set of basic plasma parameters selected, namely, minor radius of 2.25 m, major radius of 6.75 m, magnetic field on axis of 4.8 T and plasma current of 7.2 MA, should produce a reactor-grade plasma with a significant neutron flux even with the large uncertainty in plasma physics scaling from present experience to large sizes. Neutronics and heat transfer calculations coupled with mechanical design and materials considerations were used to develop a blanket and shield capable of operating at high temperature, protecting the surrounding coils, being maintained remotely and, in a few experimental modules, breeding tritium. The toroidal field coil design developed for a maximum field of 11 T at the winding combines the use of multifilamentary Nb_3Sn and NbTi superconducting cables (in high and low field regions, respectively) with forced flow of supercritical helium enclosed in a steel conduit. The poloidal magnetics system is specially designed both to reduce the toal volt-second energy requirements and to reduce the rate of field change at the toroidal field coils. The reference design was synthesized from the information developed and evaluated in our prior scoping study.[1]

Plasma

There are many ways to arrive at a set of reference parameters for a future tokamak system. The same difficulty is encountered in most of the procedures, namely, that a proven relationship between attainable plasma parameters and system size does not exist at present for the type of device under consideration. Results have been obtained from present day devices coupled with theoretical predictions, but the connection between these results and the operating parameters to be attained in an EPR-size system involves much uncertainty.

The theoretical basis used here to arrive at a reference design is straightforward and it provides a machine size which should produce reactor-grade plasma in terms of presently accepted,[2] reactor modeling calculations. The steps taken in determining the reference design are described below.

We can define safety factor q and central axis magnetic field strength B_T, as the following,

$$q = (1/A)\ B_T/B_p \quad ,$$

where A is the aspect ratio and B_p is the poloidal magnetic field strength.

$$B_T = B_{max}\ (1 - 1/A - \Delta/R_o) \quad ,$$

where B_{max} is the maximum magnetic field strength at the coil surface, R_o is the major radius and Δ is the distance from plasma edge to coil inner bore. Using these relations, we find plasma current

$$I \propto a\ [(A - 1) - \Delta/a] \quad ,$$

where a is the plasma radius. In reactors $\Delta \ll a$ is possible and the effect of Δ is, therefore, of little importance. In the EPR, however, $\Delta \sim 1.55$ m which suggests a minimum $a \sim 2.0$ m so that efficient use can be made of the volume within the toroidal coils.

Table 1 displays a summary of the key plasma related parameters in the ORNL EPR. The basic TF coil size is determined from the a and Δ presented above. The number of coils is minimized for access purposes while providing an acceptable ripple as considered in greater detail elsewhere.[3]

Table 1. ORNL EPR Reference Design-Plasma Related Parameters

Plasma radius, a (m)	2.25
Major radius, R_o (m)	6.75
Safety factor at r = a, q	2.5
Plasma current, I (MA)	7.2
Plasma shape	Circular
On axis toroidal field, B_T (T)	4.8
TF ripple, at θ= 0; r = a, δ (%)	2.2 ($\sim r^4/a^4$)
OH/EF configuration	*
OH flux change, Δφ (Wb)	185
Injection power capacity, P_b (MW)	100
Deuteron energy, E_b (keV)	200
Output power, driven, P_d (MW,th)	400
Output power, ignited, P_i (MW,th)	200**
Duty cycle (%)	>50
TF coil opening, horiz. x vert. (m)	7.4 x 10.2
Number of TF coils, N_c	20
TF coil shape	Non-circular

*Air core with electromagnetic shielding of TF coils
**For $B_p \sim A^{1/2}$

The reference system will provide containment of both 200-keV deuterons and 3.5 MeV alpha particles that is adequate from the plasma heating point of view. Additional analyses are required to determine the finite gyro-radius effects to be expected and the plasma response to them.

Figure 1 shows the P_α/P_{loss} ratio vs. time for 3 toroidal field values, 100 MW of injection, and for trapped-particle losses reduced by a factor of 10. In the reduced loss cases, ignition occurs at both 4.8 T and 4.4 T. Plasma conditions at both field levels are very similar at ignition. The 3.7 T case does not ignite and the beam power is reduced after 2 seconds to prevent β_{pe} from exceeding 1. The benefit of increased B_T is obvious. In the full loss cases, the benefit of increased field strength is also clear. Confinement is improved by operation at higher plasma currents permitted by the increased central field even though ignition is not attained. Thus the alpha particles provide a successively larger fraction of the total plasma losses as B_T increases. The uncertainty in the scaling laws used suggests a range of eventualities.

*Research sponsored by U.S. Energy Research and Development Administration under contract with Union Carbide Corporation.

MASTER

NOTICE
PORTIONS OF THIS DOCUMENT ARE ILLEGIBLE
has been reproduced from the best available copy to permit the broadest possible availability.
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED