By acceptance of this article, the publisher or recipient acknowledges the U.S. Government's right to retain a nonexclusive, royalty-free license in and to any copyright covering the article.

MASTER

CONF-791103--88

PHYSICS OF BURN CONTROL IN TOKAMAK REACTORS*

S. E. ATTENBERGER, W. A. HOULBERG
OAK RIDGE NATIONAL LABORATORY
OAK RIDGE, TENNESSEE 37830

We use a one-dimensional multifluid transport code to investigate some of the critical physics considerations for long burn times in a tokamak fusion reactor. Among these are the effects of helium ash build-up, toroidal field ripple, and fueling in the presence of a divertor. Particle and energy transport models are based on extrapolations from present day devices.

In a natural continuation of our work on start-up scenarios[1] we have begun to examine the details of an extended burn in a tokamak reactor. In the absence of trapped-particle modes, another mechanism must be found to limit the thermal excursion after ignition and provide a stable thermal burn. Possibilities include radiation, MHD activity, and enhanced ion conductivity due to toroidal field ripple.

Radiation losses may be enhanced by "doping" the plasma with impurities in order to lower the operating temperatures and increase power output. However, the presence of impurities at startup makes it difficult to reach ignition, and removal of the impurities is uncertain, so we discard this approach. MHD activity might very well control the operating temperature by enhancing transport losses when a maximum β is reached. Enhanced ion thermal conduction due to toroidal field ripple provides an externally controlled limit to thermal runaway and thus is the mechanism we investigate here.

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

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of 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. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Toroidal field ripple can cause a loss of fast ions due to vertical drift out of the plasma. This loss is primarily an energy loss for the thermal ions and can be modeled with an increase in the ion thermal conductivity in the WHIST code with the routine RIPPLE.[2] We use a general form for the ripple:

$$\delta(r, \theta) = e^{-\beta\theta^2}\{\delta(0) + [\delta(a) - \delta(0)](r/a)^3\}$$

where $\delta(0)$ = peak to average ripple on axis

$\delta(a)$ = peak to average ripple at r = a

In order to self consistently model the ripple conduction losses for a particular device, more detailed design analysis should be done. Loss of fast alphas and beam ions, and the impact of depletion of the ion tail on the reaction rate are also affected by the ripple but are not included in this analysis.

Figure 1 shows a typical start-up and burn for a reactor with a rather small ripple. Somewhat larger ripples may be tolerated by increasing the density. This reduces the ignition temperature, thereby reducing the ripple diffusion at ignition. The machine parameters used are those of INTOR, namely: major radius = 4.8 m, minor radius = 1.2 m, elongation = 1.5, toroidal field on axis = 5.0 T, plasma current = 4.0 MA. A 150 keV deuterium beam was injected at 12° from perpendicular. We assumed the following diffusion coefficients:

$$\chi_i = 3 \times \chi_i^{neo} + \chi^{ripple}$$

$$\chi_e = \frac{5 \times 10^{17}}{n_e} + 3 \times \chi_e^{neo} \quad cm^2/sec$$

$$D = \frac{1 \times 10^{17}}{n_e} + 3 \times D^{neo} \quad cm^2/sec$$

Figure 2 shows four possible burns corresponding to different assumptions about α containment. In all cases the electron density $\langle n_e \rangle$ is held fixed by feedback control. For $\langle n_e \rangle = 10^{14}$ cm^{-3} and no thermal alphas, a steady state is reached. However, if no thermal alphas escape ($\Gamma_\alpha(a) = 0$) the plasma reactivity is reduced as n_α increases and the burn quenches within about 20 sec. The plasma may also quench when the alphas are allowed to diffuse out of the system, as shown by the curve corresponding to a gradient boundary condition on the alpha density. Increasing the plasma density to $\langle n_e \rangle = 1.2 \times 10^{14}$ provides a greater margin for ash buildup and a steady state may again be reached as shown by the solid curve.

A divertor will probably be needed for impurity control in a tokamak reactor. The divertor pumps must handle an anormous load if fueling is to be done by puffing gas. Preliminary results show that fueling by pellet injection may reduce pumping requirements by an order of magnitude. This is especially important for the tritium component, which must be recovered. In fact the whole start-up phase can be done with pure deuterium, tritium being injected only after fusion temperatures are attained.

In summary, we have shown that acceptable burns occur for moderate ripple values and modest amounts of ash build-up, using transport models based on extrapolations from present day devices. Fueling and pumping requirements may be eased, especially for tritium, by using pellet injection rather than gas puffing.

REFERENCES

1. A. T. Mense, W. A. Houlberg, S. E. Attenberger, S. L. Milora, "Start-up Scenarios for Tokamak Reactors," 3rd ANS Topical Meeting on Technology of Controlled Nuclear Fusion (1978).

2. N. A. Uckan, T. Uckan, J. R. Moore, "Calculation of Magnetic Field Ripple Effects in Circular and Noncircular Tokamaks," Oak Ridge National Laboratory Report ORNL/TM-5603 (1976).