1. INTRODUCTION

High-energy fusion-product (fp) transport (e.g., alpha particle transport in D-T plasmas) is a central issue in fusion reactor development. Important effects dependent on fp transport include: the fp heating profile, a crucial factor in ignited operation [1]; possible fp-induced instabilities [2]; the high-energy fp thermalization profile and subsequent "ash" build-up [3]; fp bombardment of the first wall and the resulting plasma contamination [4].

1.1 Fusion-Product Losses

Chapters 1-7 are concerned with fp wall bombardment and focus on two types of charged, high-energy fp losses from axisymmetric tokamak plasmas: prompt and non-prompt losses. The dominant means of fp escape is due to those particles whose birth orbits immediately intersect the wall, designated *prompt* losses. Some leakage also occurs as MeV fp's slow down in the plasma and pitch-angle-scatter or diffuse across the "unstable" stagnation orbit boundary [5]. This leakage is termed *non-prompt*. Such losses are important because high-energy bombardment causes wall erosion by blistering and sputtering. In addition to potentially limiting the wall lifetime, such radiation damage injects wall material into the fusion plasma and can cause excessive radiation emission.

In Chapter 2, the derivation of the guiding center motion is discussed and orbit characteristics studied. In Chapter 3, the generalized technique for finding the loss regions is presented; example calculations for loss regions in $(v_{\parallel}, v_{\perp})$ space are presented for TFTR.* In Chapter 4, the loss boundaries are used to calculate particle bombardment of the first wall as a function of poloidal angle; sample calculations are given for PLT,* TFTR, ORNL-EPR, and UWMAK I. To confirm the validity of the model, Appendix A compares results from this work [4] to recent calculations by Ohnishi et al. [6], Kolesnichenko et al. [7], Petrie and Miley [8], and Goldston [9].

The studies of Chapters 2-4 [4] show that typical peak-to-average ratios for alpha wall fluxes range from 1.4 to 2.3 with average fluxes of $\sim 10^{14}$ -10^{15} alphas/m^2-s. The resulting localized blistering [10-11] potentially represents a serious source of plasma impurities, as well as a significant wall erosion mechanism. This realization motivated further study of these effects. Since blistering and sputtering are sensitive to the incident velocity direction as well as the flux magnitude, the fp flux versus incident velocity direction at the wall is evaluated in Chapter 5. To better understand how to control fp bombardment, we consider the sensitivity of fp wall loading to various device parameters in Chapter 6. However, other losses, induced by toroidal field ripple, become dominant in EPR and power reactor-size plasmas and have been considered by others [8,12].

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*See Table 2.1 for machine parameters.

Even so, axisymmetric losses are of interest for large reactors, because they form a lower bound, i.e. a theoretical limit for designers.

As well-confined fp's slow down in the Maxwellian background plasma, collisional pitch-angle-scattering into the velocity-space loss-region causes losses to the wall. Chapter 7 describes a crude model of this effect which consists of analytically solving the small banana-width, bounce-averaged, 2-D Fokker-Planck equation. Neglecting instability-induced losses, the relative contribution of these non-prompt losses is small. Still, the study of these losses is important as a "base case" comparison with possible instability-induced losses in future experiments, i.e. as a diagnostic for studying the slowing down mechanism(s). This formulation has been further extended in the following chapters, to model large banana-width orbits in non-circular tokamaks.

1.2 Fusion-Product Slowing-Down and Heating

Plasma heating by energetic, charged fusion products is a crucial issue for obtaining fusion reactor conditions. The evolution of alpha particle density, momentum, kinetic energy and heat flux is important in the study of start-up and ignition senarios, as well as steady-state operation. Since fast ions have large banana-width guiding-center orbits in tokamaks, the usual locally-defined particle distribution function loses its usefulness. Accordingly, the fast ion collisional slowing-down problem has been formulated in a 3-dimensional space (two velocity-space coordinates and one spatial coordinate) which describes these orbits in an axisymmetric, non-circular tokamak.

The present method consists of bounce-averaging the Fokker-Planck equation after the variables have been transformed to the three constants-of-motion (COM) which characterize the orbit of a collisionless particle [13]. The distribution function and its moments are found and since a time dependent 3-D equation is solved, it is also possible to derive scaling laws.

In Chapter 8, the theory of Rome and Peng [13] applicable to the present problem is summarized. Next, in Chapter 9, the formulation of the bounce-averaged Fokker-Planck equation is described and the slowing-down problem modeled. In Chapter 10 the source functions for 3.5-MeV alphas are calculated for sample cases, and the resulting implications discussed. Chapter 11 deals with the solution of the slowing-down problem, including both analytical and numerical results. Finally, Chapter 12 discusses the results of this work and presents the conclusions.