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Abstract

The WITAMIR-I tandem mirror reactor design utilizes protons as the ionic species in the plug plasma in order to reduce the neutron source rate there. The dominant neutron source in the barrier-plug is from central cell DT ions streaming through the barrier and reflecting off the plug potential. The axial density profile of these fuel ions is calculated in order to provide input data for neutronics calculations in the barrier and end-plug region.

I. Introduction

The WITAMIR-I[1] tandem mirror reactor design utilized an inboard thermal barrier with a yin-yang plug. The plug ions were chosen to be protons in order to avoid fusion reactions in the plug and thereby reduce the neutron shielding requirements for the yin-yang magnets and the degree of neutron streaming through penetrations, such as neutral beam lines, and into the direct convertor. The fuel ions, deuterium and tritium, from the central cell pass through the thermal barrier and are reflected by the rising potential in the plug. This will produce some rate of DT fusion in the barrier and plug; the 14 MeV neutron source in the plug cannot be entirely eliminated by choosing a non-reacting plug plasma. In this report we estimate the density of deuterium and tritium in the barrier and plug in order to provide a neutron source for neutronics calculations.

In a previous report, we calculated the potential profile in the thermal barrier. Implicit in this was the calculation of the ion density profile, although explicit results were not obtained. In this report we utilize the same formalism to calculate explicitly the fuel density, deuterium plus tritium, in the barrier and plug.

II. Model

The barrier and plug region is divided axially into three regions, as shown in Fig. 1. Region I spans from the barrier throat (peak magnetic field) to the point of minimum field. In this region the electrons are assumed to be Maxwellian with temperature T_{ec}, which is the same as in the central cell. Two different choices are made for the ion distribution function. For the first choice, we assume a collisional distribution for the passing ions

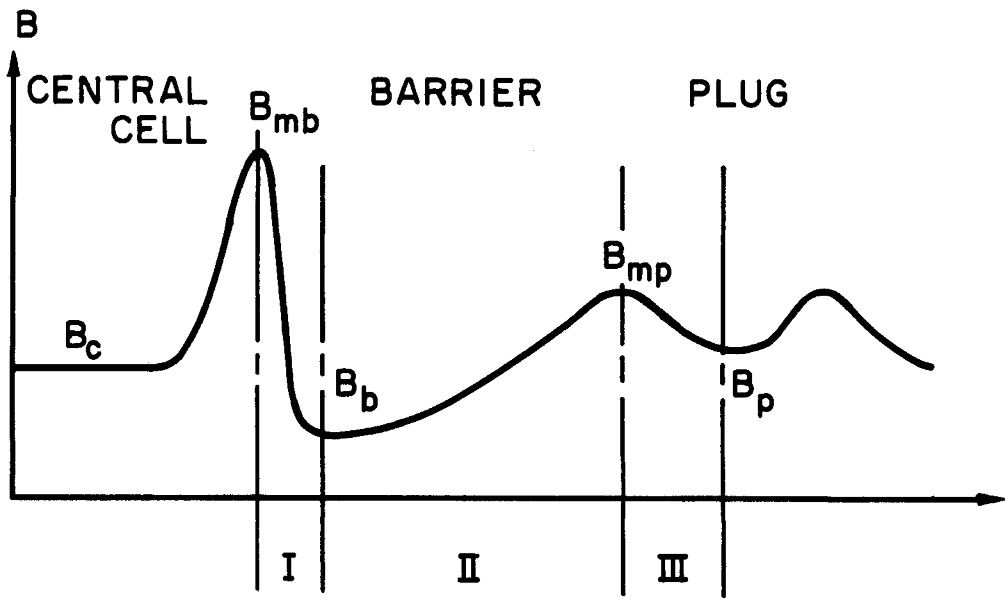

Fig. 1. Axial profile of the magnetic field in the inboard thermal barrier and plug.

$$F_i(E,\mu) = F_i \log \left[\frac{\sqrt{E - q\phi_c} + \sqrt{E - q\phi_c - B_c\mu}}{\sqrt{E - q\phi_c} + \sqrt{E - q\phi_c - \frac{B_c}{B_{mb}}(E - q\phi_{mb})}} \right] e^{-E/T_{ic}}$$

where q is the ionic charge, ϕ_c is the potential in the central cell, E is the total energy, μ is the magnetic moment, and F_i is the normalization coefficient. The second choice is to take the passing ions to be Maxwellian in the appropriate region of velocity space. These two choices appear to be reasonable limits for the possible passing ion distribution function and therefore place lower and upper bounds on the resulting ion density.

The trapped ions in the barrier will not be calculated explicitly, although their effect will be discussed in Section III.

Region II spans from the barrier minimum to the throat of the plug. The ion distribution function in this region is determined by the choice in Region I; it cannot be chosen independently. The electrons in this region consist of three "classes": electrons coming from the central cell, from the plug, and electrons trapped by the barrier potential at one end and by the magnetic field, B_{mp}, at the other end. The latter class is analogous to Yushmanov[3] trapped ions in mirrors, and are referred to here as Yushmanov electrons. The phase space for electrons in Region II is shown in Fig. 2. The electron distribution function is taken to be piece-wise Maxwellian at different temperatures. Electrons in zones M and N of Fig. 2 come from Region I and are therefore assigned the temperature, T_{ec}. Electrons in zone K came from the plug and are therefore assigned the plug temperature, T_{ep}. Electrons in zone L are the Yushmanov electrons; they are assigned the temperature T_{ec} under the

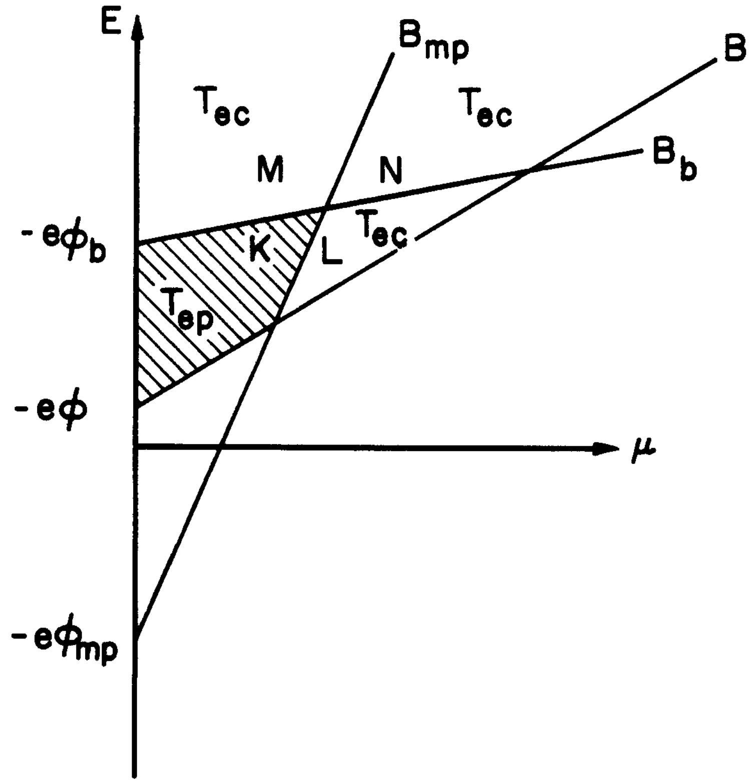

Fig. 2. Phase space for electrons in Region II.

assumption that their energy exchange is more rapid with central cell electrons than with plug electrons.

Region III is between the plug mirror throat and the plug midplane. As long as the potential profile in Region III is not calculated, we need not specify the hot ion distribution function in the plug. The midplane electron density and potential are needed, however, to calculate the contribution of plug electrons to Region II. These are taken as input data.

The calculational procedure is to integrate over the ion and electron distribution functions to obtain the local electron and ion density as functions of the local magnetic field and potential. These are shown in Figs. 3 and 4. The assumption of quasi-neutrality ($n_i(\phi,B) = n_e(\phi,B)$) then determines explicitly the potential and ion density as functions of B. Note that the spatial coordinate does not enter explicitly, but only implicitly through B(Z).

III. Numerical Results and Discussion

The total ion density (deuterium plus tritium) and electrostatic potential profile are shown in Fig. 5 for WITAMIR-I for the two choices for the ion distribution function. The ion density drops in Region I because of the expanding magnetic field and the falling potential, as expected. In Region II the ion density first rises, because of the increasing magnetic field and potential, but then peaks and starts to fall while the potential continues to rise. When the potential becomes positive ($\phi = 0$ in the central cell is the reference value) passing ions from the central cell are reflected; this causes the density to fall. Since $n_i = n_e$, it is clear that the potential and electron density in Region II do not satisfy the Boltzmann relation. This is because the electron distribution function is non-Maxwellian; it is only

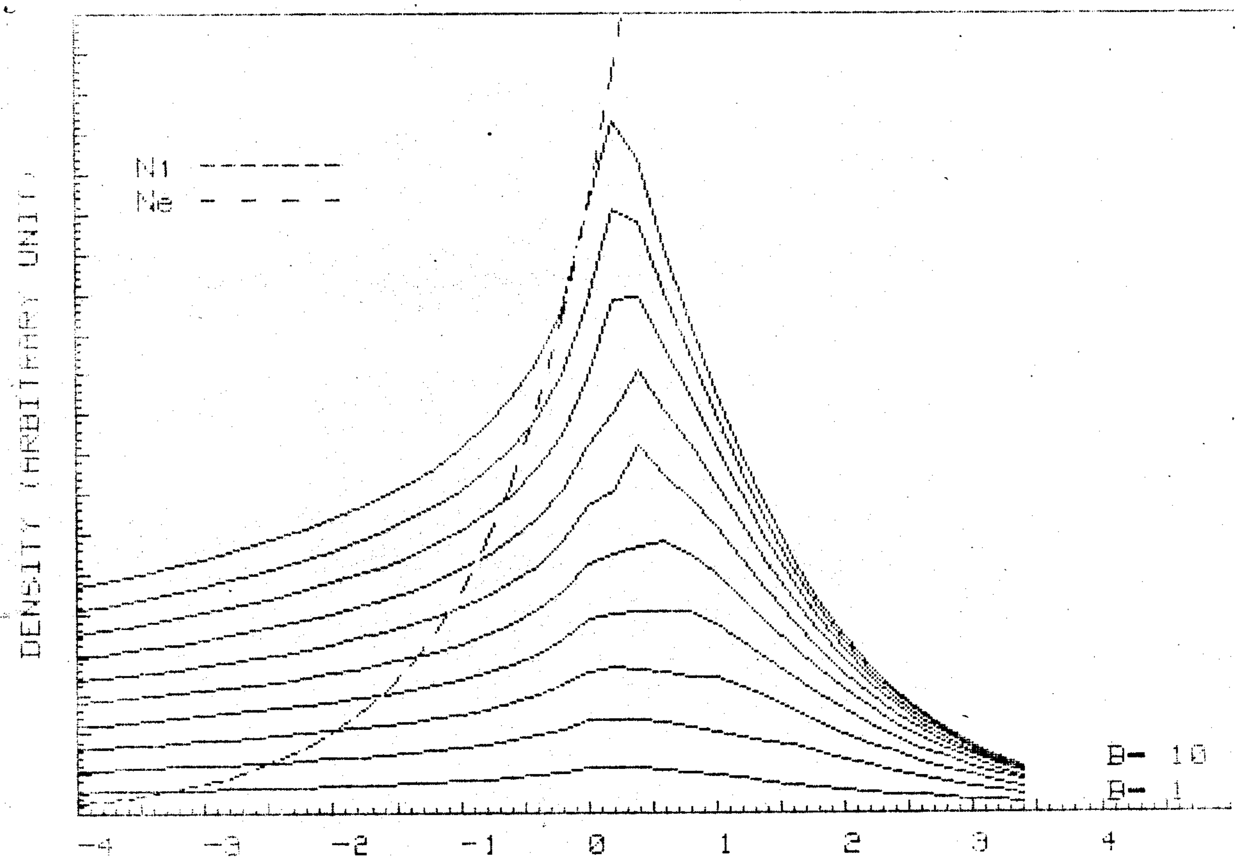

Fig. 3. Ion and electron density versus potential and magnetic field stength in Region I for the collisional ion distribution.

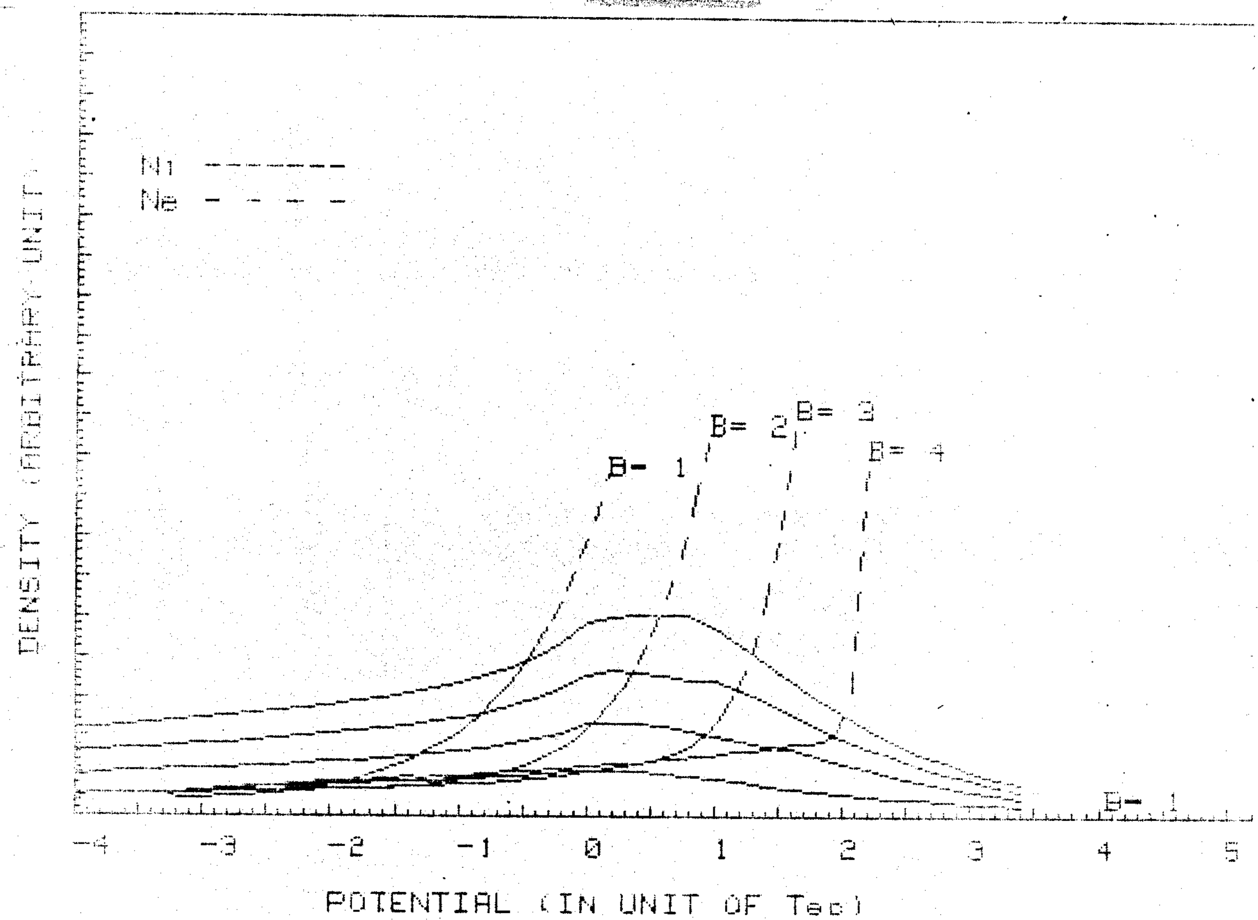

Fig. 4. Ion and electron density versus potential and magnetic field strength in Region II for the collisional ion distribution function.

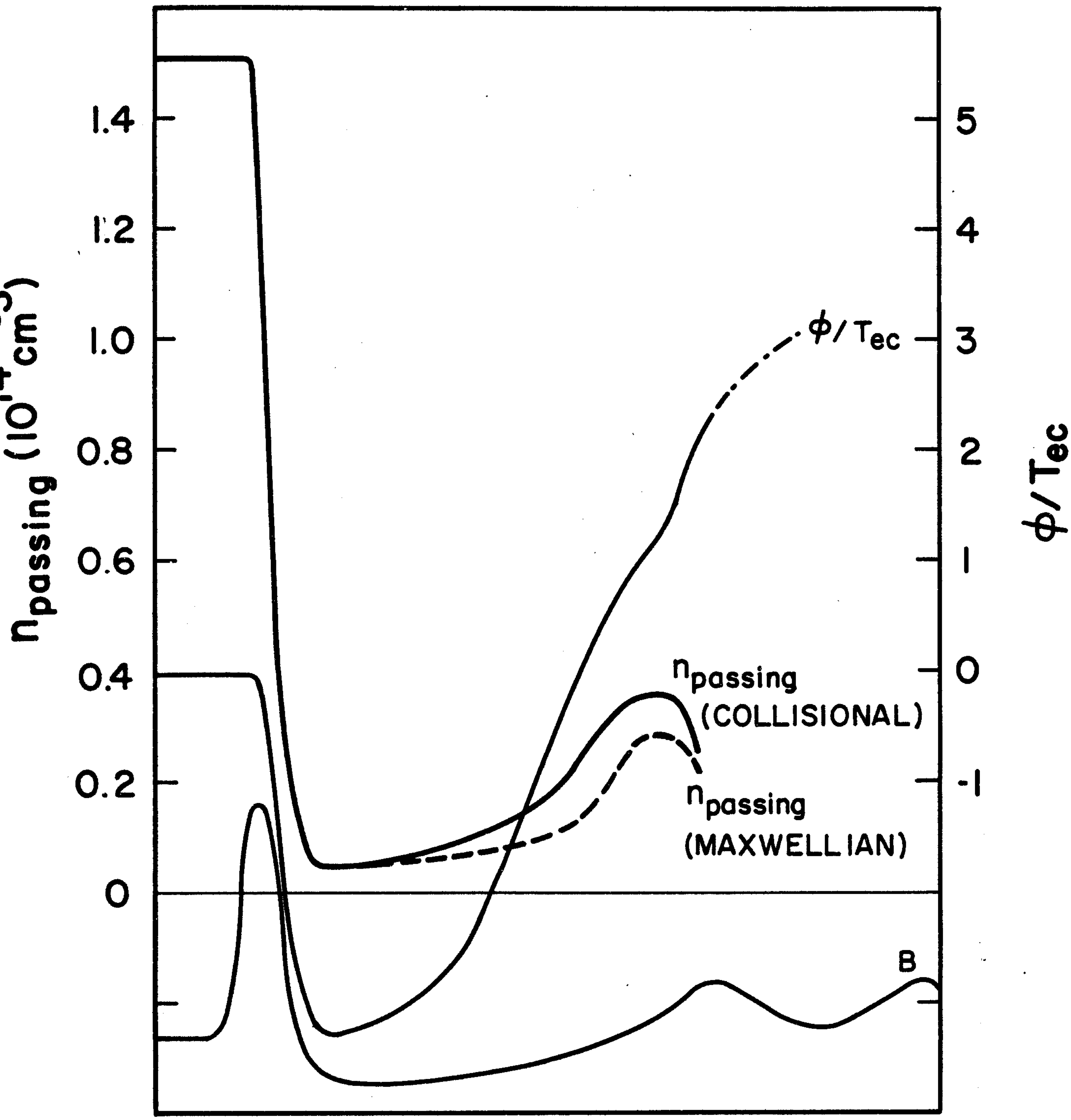

Fig. 5. Axial profile of the passing ion density and potential in the WITAMIR-I thermal barrier.

piece-wise Maxwellian with the "colder" (i.e. temperature equal to T_{ec}) electrons at the higher kinetic energy than the "hotter" electrons at temperature T_{ep}.

Ions trapped in the thermal barrier will add to the ion density shown in Fig. 5. They will contribute most near the bottom of the barrier but should not contribute much where $\phi > 0$, since the trapped ions are mostly trapped by the potential. Consequently the trapped ions should not affect the magnitude or location of the density peak near the throat of the yin-yang magnet. Since the neutron source rate is proportional to the square of the density, the peak value and location are more important for neutronics calculations. The peak density in the barrier is about one-fifth the central cell density. The significance of this density peak as a neutron source depends on its location relative to beam lines and other penetrations and is determined by detailed three-dimensional neutronic calculations. This is outside the scope of this report and will be reported separately.

Acknowledgments

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