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Comments on
Proposed Experimental Study of Fusion
Product Losses from PLT and TFTR Plasmas

by

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October 1978

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The measurement of fusion product (fp) leakage from PLT and TFTR plasmas has been proposed [1] as a critical experiment for future reactor development. Fusion rates are sufficient to carry out such experiments with either deuterium or D-³He plasmas in these devices. This would provide important data about fp transport prior to contamination of TFTR with tritium for D-T experiments (making experimental access much more difficult). Such an experiment would provide the first actual data about the accuracy of present fusion product transport calculations and the possible occurrence of instabilities driven by the high-energy alphas. This is particularly true in light of the prediction by Chan and Sigmar [2] of large non-prompt losses due to α -driven (low frequency) Alfvén waves. More recently, Mølviq and Sigmar [3] have predicted that α -driven (high frequency) electrostatic instabilities will cause anomalous slowing down at a rate much faster than collisional. Enhanced α losses, due to trapping in B-field ripple [4,5] have also been predicted. The detection of anomalously small or large losses can be used to identify the slowing down mechanism(s). By understanding this physics, engineering designs can be modified to control excess losses or enhance anomalously fast slowing, in order to achieve reactor conditions.

Hively and Miley [6,7] have analyzed an experiment involving two detectors (one at the top and one at the outboard side of the torus; see Fig. 1), shielded, and facing away from the plasma (to minimize background radiation), so that fusion products can enter along gyro-helices [8]. The analysis is for prompt losses and while similar to their previous analysis for wall bombardment [9] is complicated by the need to evaluate two factors: (a) the differential fraction, f_ℓ , of fusion products reaching the vicinity of the detector from each interval of plasma volume, and (b) the fraction of (a)

that can gyro-orbit (with proper gyrophase and pitch angle) through the collimator defined by the shielding. The number of particles-detected-per-second, $\dot{N}$, is a summation of these contributions over the plasma volume:

$$\dot{N} = \int_V d^3r n_1 n_2 \langle \sigma v \rangle_{12} \int_0 dA p_d (df_g/dA); \quad (1)$$

where p_d is the detection probability associated with (b), above; the integral $\int_0 dA (\dots)$ is taken over the area in the r - θ plane (detection region) through which the drift-orbit guiding centers must pass so that fp's can gyro-orbit around the radiation shield and be detected; and df_g/dA is the prompt-loss-fraction-per-unit-area in the detection region.

$\dot{N}$ is proportional to the toroidal magnetic field, B_0 . Sample calculations of 0.83 MeV He^3 in PLT show that as the plasma current, I_{p1} , increases, $\dot{N}$ rises rapidly, peaks, then falls monotonically (see Fig. 2). Few particles are detected at low I_{p1} because the radiation shield only admits particles (with corresponding pitch angles χ , $0.6 \leq \sin \chi \leq 0.99$) born at the plasma edge. As I_{p1} increases, more particles from the plasma core are detected (see Fig. 3). Further increases in the current cause $\dot{N}$ to fall because the loss fraction decreases as $\sim 1/I_{p1}$. As expected, it is also found that $\dot{N} \sim \langle \sigma v \rangle$, corresponding to the average ion temperature of the plasma. Thus $\dot{N}$ is a measure of the α source function.

Present reactor designs are based on the flux-conserving tokamak (FCT), having $\beta > 5\%$, for which the model of Ref. 9 is inaccurate. Recent work by Hively [10] models fp transport in such high- β devices, using the constants-of-motion formulation of Rome and Peng [11]. We propose to apply Hively's

model to the detection of fp losses in FCT devices. The proposed work would ultimately include collisional slowing down and pitch-angle scattering in an arbitrary non-circular tokamak equilibrium. This will form a "base-case" against which to compare experimental results for any anomalous effects.

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Figure 1. This is the detector arrangement at side and top diagnostic ports of the tokamak; also shown is the schematic detection of a high-energy fp at the side detector.

Figure 2. Number of 0.82-MeV ^3He seen (relative units) is plotted versus plasma current for various centerline toroidal field values (kG) in PLT (deuterium plasma).

Figure 3. The drift orbits shown here are for the pitch angle, $\chi = \arcsin(.654) = 40.7^\circ$, as well as intermediate values; the number on each curve is the pitch angle at the detector. Orbits having $\chi > 90^\circ$ are not shown because these trapped orbits lie mostly outside the plasma and intersect the wall.