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BY

D.S. DARROW, R. MAJESKI, N.J. FISCH, ET AL.

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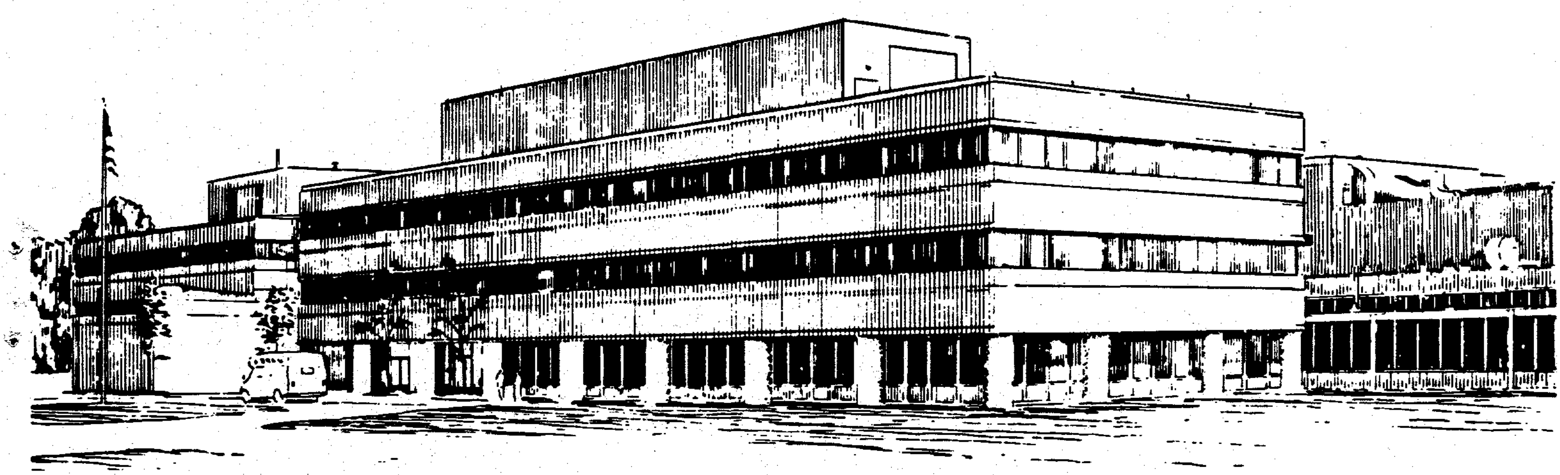

PRINCETON UNIVERSITY, PRINCETON, NEW JERSEY

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# Enhanced Loss of Fusion Products During Mode Conversion Heating in TFTR

D. S. Darrow, R. Majeski, N. J. Fisch, R. F. Heeter, H. W. Herrmann, M. C. Herrmann, M. C. Zarnstorff, and S. J. Zweben

*Princeton University, Plasma Physics Laboratory, PO Box 451, Princeton, New Jersey 08543-0451, USA*

## ABSTRACT

Ion Bernstein waves (IBWs) have been generated by mode conversion of ion cyclotron range of frequency (ICRF) fast waves in TFTR. The loss rate of fusion products in these discharges can be large, up to 10 times the first orbit loss rate. The losses are observed at the passing/trapped boundary, indicating that passing particles are being moved onto loss orbits either by increase of their $v_\perp$ due to the wave, by outward transport in minor radius, or both. The lost particles appear to be DD fusion produced tritons heated to ~1.5 times their birth energy.

## INTRODUCTION

IBWs have been produced in TFTR by mode conversion of ICRF fast waves in plasmas with large fractions of $^3$He, for the purposes of electron heating and current drive.[1] The mode conversion occurs at the two-ion hybrid layer, and the resulting IBW is absorbed by electrons within a few cm of the mode conversion layer. The major radius of the mode conversion layer can be controlled by varying the toroidal field strength and the fractional abundance of $^3$He (the remainder of the plasma being principally D and $^4$He). Typical discharge conditions are: R=2.625 m, a=0.99 m, $B_T$=4.8 T, $I_p$=1.4 MA, $n_e(0)=5\times10^{19}$ m$^{-3}$, $n_{3He}/n_e\geq0.1$, $T_e(0)$=7 keV, $P_{NB}$=0–10 MW, and $P_{RF}$=3–5 MW (43 MHz). Under some conditions, enhanced losses of charged fusion products (CFPs) are seen at the wall during these experiments. The CFP loss rate is measured by detectors at 90°, 60°, 45°, and 20° below the outer midplane, at a single toroidal location.[2] Each detector measures the total flux and the gyroradius and pitch angle distributions as functions of time. They are, however, unable to discriminate between ions of different charge or mass if they possess the same gyroradius.

## CHARACTERISTICS OF THE LOSS

Figure 1 compares the time histories of two similar IBW discharges. The only difference between them is in the fraction of $^3$He present. The solid line shows data from a discharge with 67% $^3$He in the gas puffed into the vessel, while the broken line is for one with 50% $^3$He. The total CFP loss rate for the discharge with 67% $^3$He puffing exceeds that in the other on all detectors by up to a factor of ten. The losses in the comparison shot are about at the level of first orbit loss, ~10% of the CFP birth rate.[3] The variation of the losses appears to be correlated with small changes in the edge density, and may relate to the coupling or propagation of waves in the edge. Another comparison shot, like those shown but with no NBI, has no detectable losses. This indicates that the losses are indeed fusion products, since these detectors are insensitive to beam ions and there is no rf-produced energetic tail. From Fig. 1, it is clear that the loss rate can transiently be a substantial fraction of the source rate. Such large losses in a reactor might damage the first wall.

Figure 2 compares the pitch angle distribution of the loss to the 90° detector during IBWH with a normal first orbit loss distribution. The loss during IBWH is centered at the pitch angle of the passing/trapped boundary for this detector, and the width of the distribution is equal to the instrumental width. Loss at the passing/trapped boundary would be seen if the CFPs are being transported outward in minor radius[4] or if they are being given additional $v_\perp$ by the IBW.[5]

Figure 3 compares the gyroradius distribution of the loss in the 90° detector during IBWH to first orbit loss. The first orbit loss distribution shows the effect of instrumental broadening, since it consists of only birth-energy particles. The distribution during IBWH peaks at a higher gyroradius and has a larger FWHM than does the first orbit loss distribution. Both indicate that escaping particles have been significantly heated. The observed gyroradius distribution matches that of CFPs at 50% above their birth energy.

## SPECIES INVOLVED

The losses described above have been seen in plasmas which are principally composed of $^3$He, $^4$He, and D, with D neutral beams. Hence, there will be both DD and D$^3$He fusion products present which may be lost. However, some features of the detector system allow the range of species involved to be narrowed.

The D$^3$He fusion products are a 14.7 MeV proton and a 3.7 MeV alpha particle. The DD CFPs are a 3 MeV proton, 1 MeV triton, and 800 keV $^3$He ion. Of these, the 14.7 MeV proton can be eliminated since its gyroradius does not match that seen, and it contributes negligibly to the total signal. The 800 keV $^3$He ion cannot enter the detectors unless it is heated to ≥900 keV, and even then its gyroradius does not match the observations. Hence, it can be omitted from consideration. The remaining particles, the 3.7 MeV alpha, the 3 MeV proton, and the 1 MeV triton, cannot be excluded based upon detectability. All have similar gyroradii as well.

If the D beams are replaced with T beams, the IBW-related loss appears to vanish. Two possibilities might explain this change: (1) the loss has, in fact, stopped; or (2) the loss is still present, but is overwhelmed by the loss of DT alpha particles. This, we suggest, makes it unlikely that the observed losses are due to the 3.7 MeV $D^3He$ alpha particle. T beam injection produces alpha particles at 3.5 MeV, an energy only 6% different from the $D^3He$ alphas. Since the process involved increases the lost particles' energies by ~50%, we expect the loss process to work equally well with DT alphas as with $D^3He$ alphas. Yet, with a substantially larger source of alphas, the loss does not grow but remains the same or vanishes. Hence, we conjecture that the IBW-related losses are not of alpha particles.

This leaves the DD CFPs, 3 MeV protons and 1 MeV tritons, as possibilities. Of these two, the plasma conditions are such that there will be a $2\Omega_T$ resonance at R=3.00 m, while there will be no proton cyclotron resonance in the plasma at all, favoring the hypothesis that the losses are of energetic tritons.

## POTENTIAL FOR CONTROL OF $\alpha$ PARAMETERS

The above results indicate that there is a strong interaction between the IBW and CFPs under appropriate conditions. This interaction might have use in ash removal, burn control, current drive, and transfer of the alpha particle energy to plasma ions.[6] In this last case, the object would be to improve the reactivity of a plasma by direct transfer of alpha energy to the ions, while at the same time transporting the alphas toward the plasma edge where they would eventually be pumped out. Considerable further experimentation, analysis, and modeling will be required before the intriguing results reported here can be applied to practical needs.

## ACKNOWLEDGEMENT

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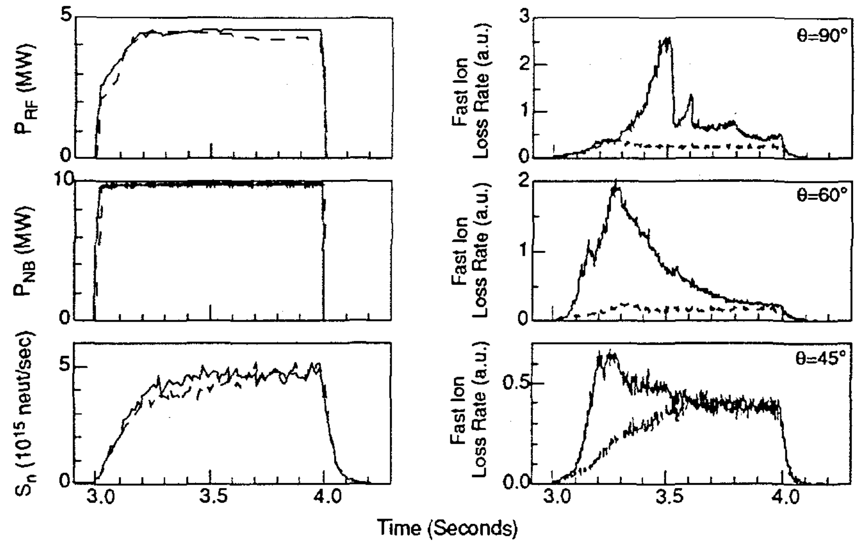


**FIGURE 1.** ICRF power, neutral beam power, neutron rate, and fast ion loss rate to detectors 90°, 60°, and 45° below the outer midplane for two similar discharges in TFTR. The shot plotted with the dashed line (81548) had 50% $^3$He in its gas fueling, while the shot plotted with the solid line (81547) had 67% $^3$He gas fueling.

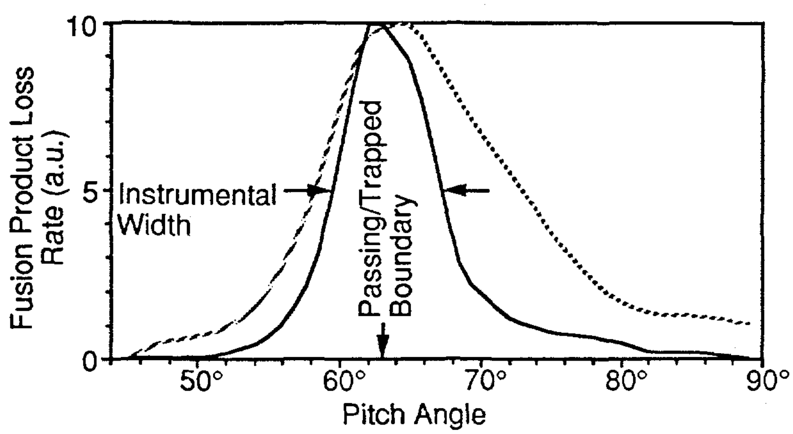


**FIGURE 2.** Pitch angle distributions of the IBW-related loss (solid line) and first orbit loss (dashed line) in the 90° fast ion detector. The IBW loss is centered at thepitch angle of the passing/trapped boundary, and its width is due to instrumental broadening. The IBW loss has been normalized to the amplitude of the first orbit loss in this figure.

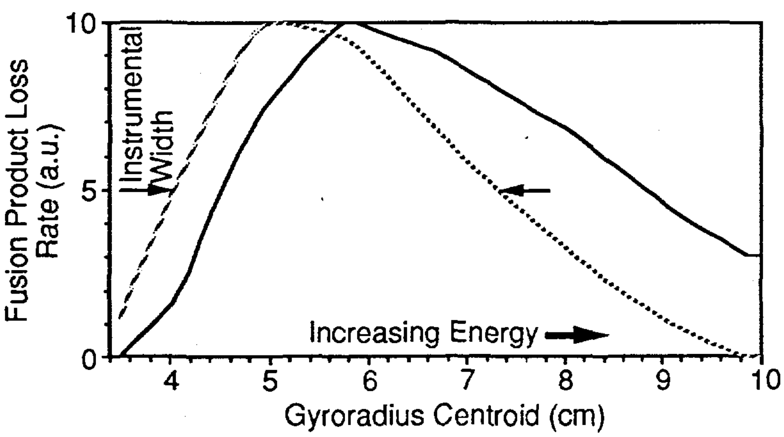


**FIGURE 3.** Gyroradius distributions of the IBW-related loss (solid line) and first orbit loss (dashed line) in the 90° detector. The width of the first orbit loss distribution is due to instrumental broadening, and its peak is at the gyroradius corresponding to birth-energy charged fusion products. The IBW loss case peaks at a higher gyroradius and is broader, both indicating significant heating of the fusion products before their loss.

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