MEASUREMENTS OF ESCAPING ALPHAS IN THE TFTR DT EXPERIMENTS

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2. Alpha Loss in the 45° Detector

The DT alpha loss to the detector 45° below the outboard midplane is shown vs. plasma current in Fig. 3 for the same plasmas of Fig. 1. In contrast to the results at 90°, the neutron-normalized alpha loss at this location does *not* follow the predicted first-orbit alpha loss vs. plasma current. This behavior is not due to any "collective" alpha effect, since the alpha loss at 45° is independent on the DT neutron rate at a fixed current, and since a similar current dependence is obtained for DD fusion products. Therefore this behavior is a "single particle" effect, possibly due to stochastic toroidal field (TF) ripple diffusion, such as analyzed previously for the midplane (20°) detector in DD[5].

However, calculations of stochastic TF ripple diffusion in TFTR done using the collisionless bounce-averaged MAPLOS code[5] predict that the collisionless TF ripple loss should occur at poloidal angles ≤30° below the outboard midplane, so can not explain the non-first-orbit loss component at 45° in Fig. 3. The collisional guiding center code ORBIT predicts higher TF ripple loss than MAPLOS, with a global alpha loss at Ip=1.8 MA about a factor of 3 above the first-orbit loss, but also predicts that this TF-ripple-induced loss should be ≤30° below the outboard midplane[6]. Thus neither code is presently able to explain the trend shown in Fig. 3.

3. Time Dependence of Alpha Loss

The time dependence of the alpha loss in the 90° detector follows closely the time dependence of the DT neutron rate during and after NBI, as expected from first-orbit loss. For the 45° detector there is a gradual ≈50% increase in the alpha loss rate per neutron over ≈1 sec during NBI, but no large increase after NBI. This may be consistent with the relatively rapid process of stochastic TF ripple diffusion (≤10 msec), but not with a significant collisional loss over the timescale of alpha thermalization (≈0.6 sec). There was also no significant change in the gyroradius distribution after NBI in either detector, such as might be calculated from a delayed loss process.

The alpha loss in the DT discharges described above was not visibly affected by coherent MHD activity. The clearest examples of MHD-induced alpha loss have occurred during major and minor disruptions, as seen previously for DD fusion products[1]. Fig. 4 shows the alpha loss in the 90° detector increasing by a factor of ≈100 above the first-orbit loss level just before a major disruption. This pre-disruptive alpha loss could be a problem for ITER, since the alphas may be lost at different places than the thermal plasma. No DT alpha particle loss associated with Alfven waves, such as the TAE mode, has yet been seen[7].

Measurements of Escaping Alphas in the TFTR DT Experiments

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Alpha particle loss to the wall of TFTR has been measured during the initial TFTR DT run period. These measurements were made with the same lost alpha scintillator detector system used previously for DD fusion products[1], except for a switch of the scintillator material from zinc sulfide (P31) to yttrium aluminate (P46) to insure a linear response up to the maximum alpha flux expected in DT[2]. The alpha loss signals in DT are ≈100 times larger than the DD fusion product loss signals, as expected from the neutron rates and the relative sensitivity to DT vs. DD fusion products.

1. Alpha Loss in the 90° Detector

The DT alpha loss at the vessel bottom 90° below the outboard midplane is generally consistent with the calculated first-orbit loss of 3.5 MeV alphas. This is illustrated in Fig. 1, which shows the total alpha loss rate to the 90° detector normalized to the DT neutron rate as a function of plasma current (R=2.52 m). When the data at Ip=0.6 MA are normalized to the calculated first-orbit loss to this detector, the data at Ip=1.0-2.5 MA fit the calculated first-orbit loss to within the joint uncertainties in measurement and modeling (≈30-40%). The absolute value of the alpha loss at 90° in DT is also consistent with this model, at least to within the factor-of-two uncertainty of an absolute detector calibration. The alpha loss per neutron at Ip=2.0 MA does not change more than ≈20% over the entire range of DT neutron rates from 2% tritium to 50/50 DT, i.e. over ≈0.05-2.2×10^{18} neutrons/sec, indicating the absence of any collective alpha loss mechanism in these plasmas with $\beta_\alpha(0) \leq 0.25\%$.

The measured pitch angle and gyroradius distributions for DT alpha loss in the 90° detector are shown in Fig. 2 for a discharge at Ip=2.5 MA with 7.4 MW of fusion power. The distributions in DT are consistent with the expected alpha particle first-orbit loss, the peak of which is calculated to be at the "x" in the figure. Also shown in Fig. 2 is a DD discharge with the same plasma parameters and a fairly similar loss pattern, as expected for DD fusion products, but with a small "delayed loss" feature similar to that previously observed in DD[3]. The apparent absence of this delayed loss in the 90° detector in DT is at least qualitatively consistent with the hypothesis that in DD it was due to classical collisional pitch angle scattering of the 1 MeV tritons, which is much reduced for 3.5 MeV alphas[1,4].

4. Discussion

The DT alpha loss detected 90° below the outboard midplane is consistent with the expected first-orbit loss, while the alpha loss detected 45° below the outboard midplane is significantly higher than the expected first-orbit loss. In all cases the relative alpha loss per neutron does not vary significantly with the DT neutron rate, so the non-first orbit losses at 45° are not due to any collective alpha particle effect.

Somewhat similar non-first orbit loss was previously described for DD fusion products in the 20° detector, and was explained in terms of collisionless stochastic TF ripple diffusion[5]. The recent guiding center code calculations of collisional TF ripple-induced alpha loss have shown a significant collisional alpha loss effect[6], but have not yet explained the increased alpha loss seen at 45°. Such calculations have predicted the loss of neutral beam ion loss in JT-60U[8], and will be continued with improved modeling of the TFTR magnetic fields and better statistics. Fokker-Planck calculations are also in progress to model the collisional loss into these detectors[9].

So far there have been no signs of any alpha particle loss associated specifically with full DT operation, such as might have been expected from collective alpha particle instabilities. Experiments designed to stimulate such instabilities are reported elsewhere[10].

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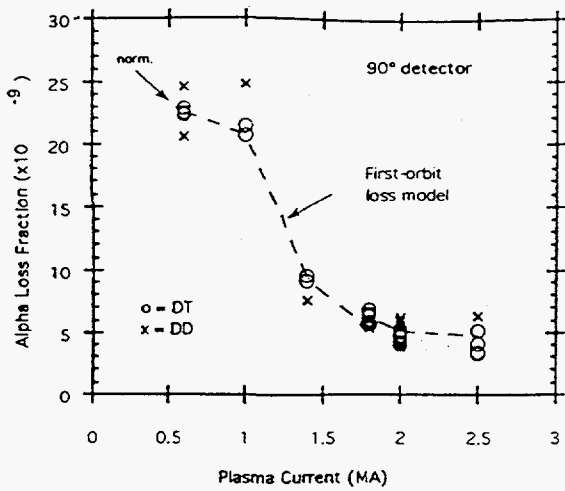10. E. D. Fredrickson, this conference

Fig. 1: The total alpha particle loss 90° below the midplane vs. I_p. The vertical axis is the calculated alpha loss fraction into this detector, e.g. $\approx 10^{10}$ alphas/sec for an I_p= 2.0 MA discharge with 2×10^{18} neutrons/sec.
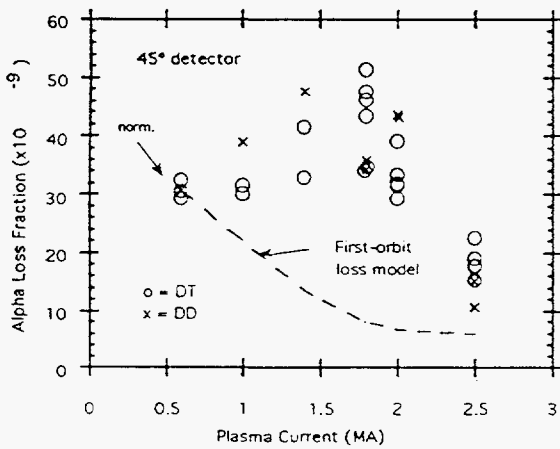

Fig. 3: The total alpha particle loss 45° below the midplane vs. I_p. Since a similar non-first orbit loss vs. current is seen in DD, this is a "single particle" and not a "collective" alpha effect.
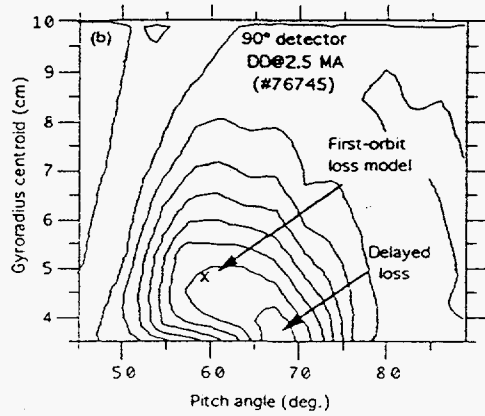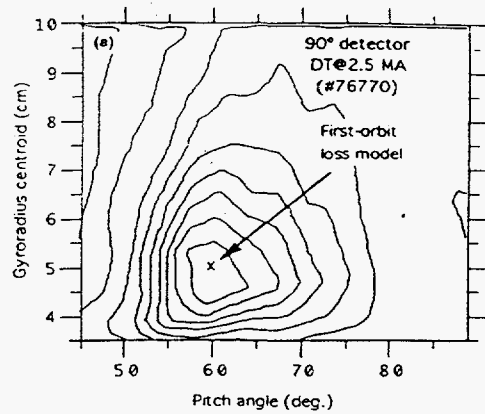

Fig. 2: Pitch angle vs. gyroradius distributions of alpha loss at I_p=2.5 MA for similar DT and DD discharges at R=2.52 m. In DT the pattern is consistent with first-orbit loss when the instrumental broadening effects are included. The delayed loss in DD which is not seen in DT is most likely due to collisional losses of 1 MeV tritons in DD.
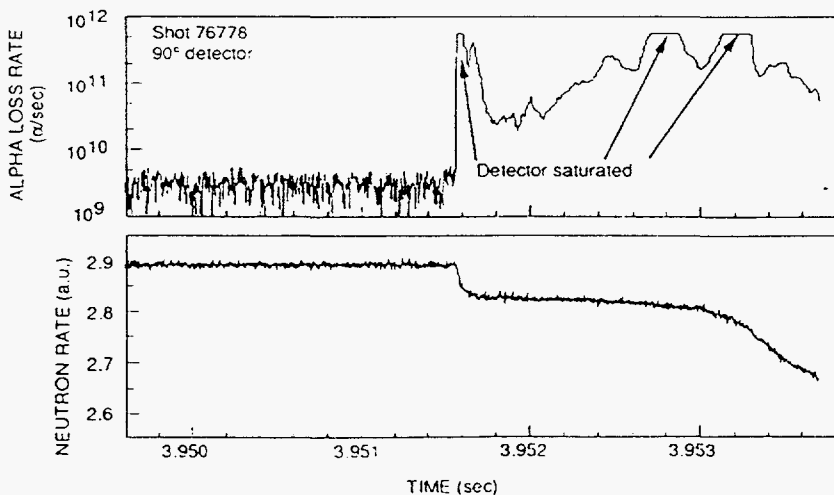

Fig. 4: Time dependence of the DT alpha loss at 90° during a high power disruption at I_p=2.5 MA. There is a factor of ≈ 100 increase in the alpha loss a few msec before the start of the plasma current decay. The alpha loss at 90° was larger than the loss in the other detectors.

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