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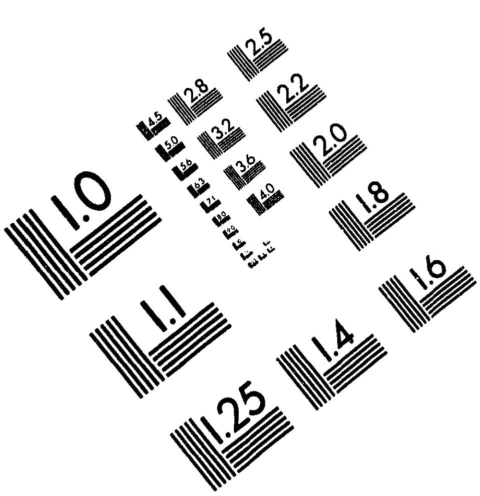

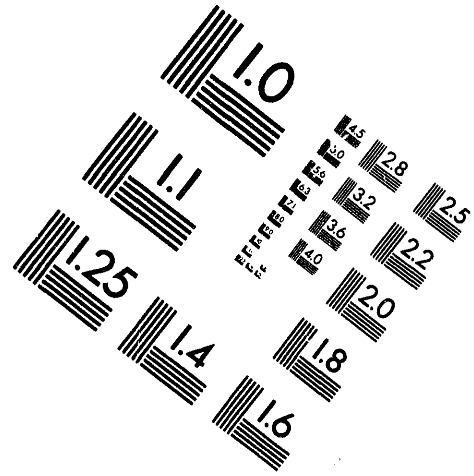

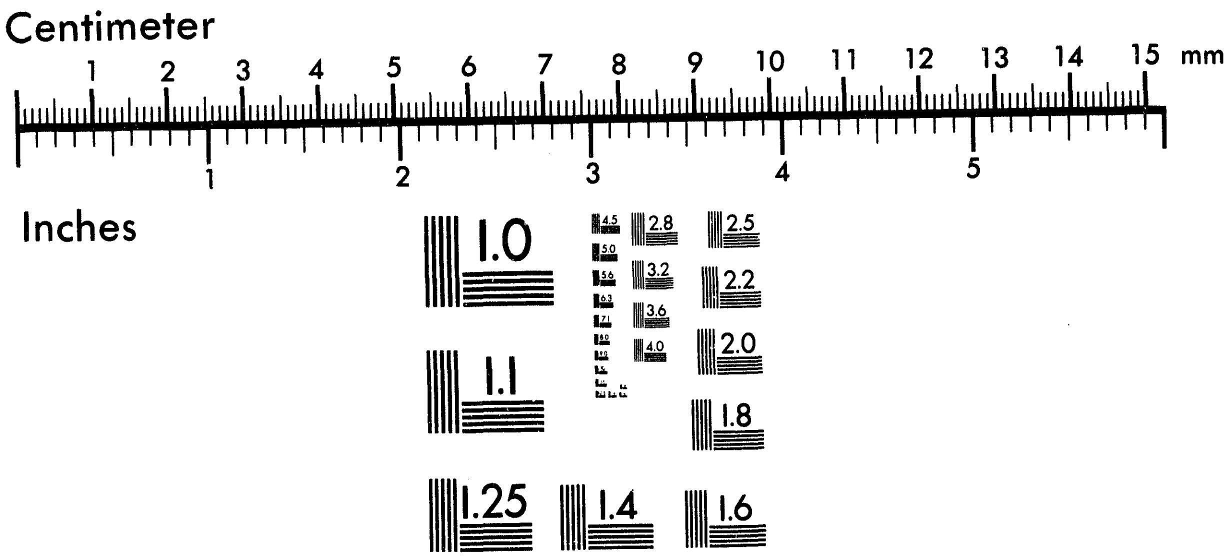

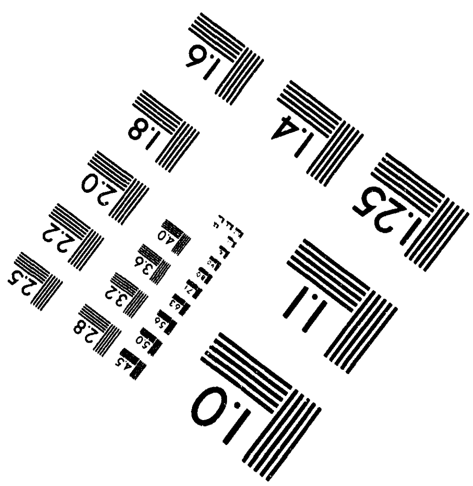

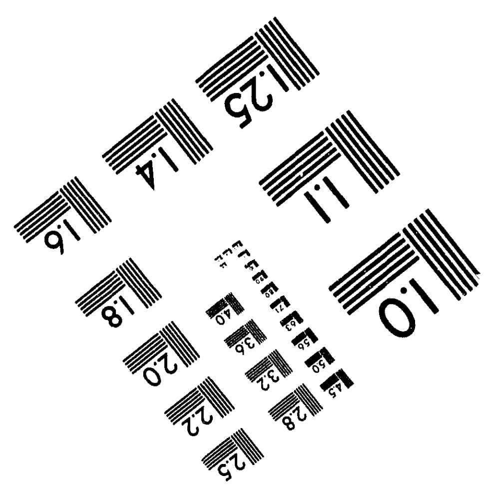

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TRITIUM TRANSPORT STUDIES ON TFTR

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Introduction

Recent publications illustrate the present state of the art in studies of particle transport of electrons [1] and impurity ions [2] by perturbative techniques. After perturbing the steady state density $n(r)$ of a given species by means of a small gas puff or laser blowoff, the observed transient behavior of the relevant density profile is used to determine the particle flux $\Gamma(r,t)$ from the continuity equation,

$$\frac{\partial n}{\partial t} = -\nabla \cdot \Gamma + S,$$

where S is the source term. At each radius, a regression analysis is then applied to deduce the transport coefficients $D(r)$ and $V(r)$ according to the relationship

$$\delta\Gamma(r,t) = -D(r)\,\delta\nabla n(r,t) + V(r)\,\delta n(r,t).$$

The success of this method rests on the ability to determine particle density profiles and source functions with adequate temporal and spatial resolution. In the case of electrons, interferometry is the standard diagnostic. Charge exchange recombination spectroscopy provides the needed accuracy for studying impurity species, such as He^{2+} or Fe^{24+}. However, these techniques can not be applied to hydrogenic species.

Strachan, *et al.* [3,4] have used nuclear techniques to study transport of reactive species. Their results demonstrated the applicability of the method, although with very limited spatial resolution. Spatially resolved profiles of D-D and D-T neutrons have been reported on JET, where tritium was introduced either by neutral beam injection or by recycling from the walls during tritium cleanup experiments [5,6]. It was concluded that the particle transport properties of tritium are very similar to those of deuterium.

This paper reports the first results of tritium transport studies on TFTR. Gas puffs of either pure tritium or trace-tritium (2% T_2 and 98% D_2) were injected into low-recycling deuterium neutral beam heated plasmas, referred to as supershots, and the temporal and spatial evolution of the resulting 14.1 MeV $t(d,n)\alpha$ neutron emission was measured. Because of the high reactivity of tritium with energetic deuterons, small gas puffs are sufficient to provide a significant increase in neutron emissivity without seriously perturbing other plasma parameters. By analyzing the time evolution of the D-T neutron emission profile after a gas puff, the local tritium density may be inferred.

In order to compare with earlier work on TFTR, we chose plasma conditions to closely match those of the supershots studied in Ref. 2. A total of ≈ 14 MW of deuterium neutral beams, with a maximum energy of ≈ 100 keV, were injected both co-tangential and counter-tangential with respect to plasma current, to minimize plasma rotation. The plasma had a toroidal field strength of 4.8 T, a major radius of 2.45 m, a minor radius of 0.8 m, and a plasma current of 1.15 MA. The central electron and ion temperatures were 7.5 keV and 25 keV, respectively, and the central electron density was 5×10^{19} m^{-3}. Global energy confinement time was 0.16 s, which is about three times the L-mode scaling value. Neutral beam injection was from 3 to 4 s, and the tritium gas puff (≈ 300 torr-liter/s for 0.016 s) was applied at 3.5 s.

Measurements

Spatial profiles of 14.1 MeV neutrons after a tritium gas puff are measured with the TFTR multichannel neutron collimator. The system consists of three arrays of detectors, housed in a massive shielding structure in the facility basement, which view the plasma vertically through ten collimated flight tubes. One of the arrays (10 detectors) uses NE-451 (ZnS) scintillators [7,8]. A second 10-channel array uses less sensitive ZnS wafer scintillators, developed at Princeton [9]. Taken together, the two scintillator arrays have dynamic range sufficient to cover all TFTR operating conditions. They can not distinguish between 2.5 MeV and 14.1 MeV neutrons, although they are more sensitive to the latter. The third array, consisting of five ^{4}He proportional counters [10,11], can discriminate against 2.5 MeV D-D neutrons but has more limited dynamic range. The proportional counters and NE-451 scintillators were absolutely calibrated *in situ* [11,12], using a D-T neutron generator inside the TFTR vacuum vessel [13]. The array of less sensitive scintillators was cross-calibrated, using plasmas with low power trace-tritium neutral beam injection [14]. The estimated absolute uncertainty of neutron measurements for each chord is ±15%.

During the trace-tritium gas puff experiments, the ^{4}He proportional counters could unambiguously detect the 14.1 MeV neutrons from $t(d,n)\alpha$ reactions in the presence of a large background of 2.5 MeV $d(d,n)$ ^{3}He neutrons. Although count rates were somewhat lower than optimal and only 5 detectors were available, the measurements showed that ≈ 15% of the injected gas entered the plasma and that the recycling coefficient for tritium was < 2%. In the course of a series of discharges with trace-tritium gas puffs, the 14.1 MeV neutron emission before a puff gradually increased but remained small compared to the increase during a puff.

For pure tritium gas puffs, the increase in count rate in the scintillators was of the same order as the count rate before the puff, while there was no observable increase in count rate in similar plasmas with deuterium gas puffs. To improve statistical accuracy, five shots with pure tritium puffs were averaged and compared to averages of four nominally identical plasmas with deuterium gas puffs. The difference in count rate for each measurement chord represented D-T neutrons from the tritium puff,

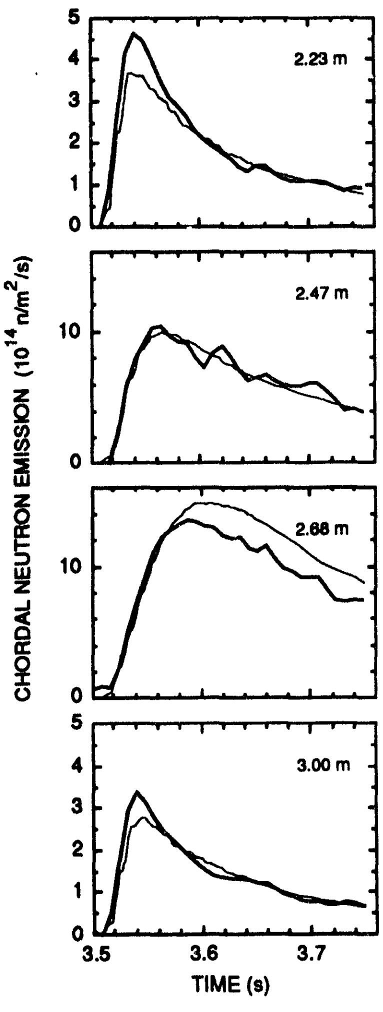

Fig. 1. Emission of 14.1 MeV neutrons along four chords through a TFTR D-D supershot after injecting a puff of pure tritium gas. Heavy lines: measurements. Thin lines: TRANSP simulation using He^{2+} transport coefficients.

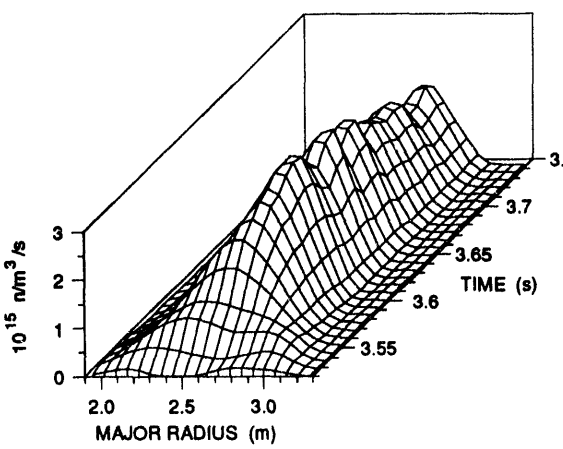

Fig. 2. Volume emission rate of 14.1 MeV neutrons from a TFTR D-D supershot after injecting a puff of pure tritium gas. Values are obtained by Abel inversion of chord-integrated measurements.

irrespective of residual recycling from previous discharges.

Figure 1. shows chord-integrated neutron emission *vs.* time for the four central measurement chords. The magnetic axis was near the 2.68 m position. Clearly, the neutron emission rises and declines earlier on the outer chords than on the inner ones. The thin lines in Fig. 1. are TRANSP [14] simulations of chord-integrated D-T neutrons, using transport coefficients previously reported for He^{2+} [2]. The simulations have been normalized to give the same peak global source strength as the measurements. Although there is general agreement between measurements and simulations, the measurements show a larger early rise and decay on the outer channels than the simulations and less central peaking late in time.

By Abel inverting the chordal measurements, we obtain radial profiles of 14.1 MeV neutron emission from the puff, as shown in Fig. 2. The profiles evolve from centrally hollow immediately after the puff to a centrally peaked shape in ≈ 100 ms, and then slowly decay in magnitude. Figure 3 shows an overlay of contour plots of local D-T neutron emissivity obtained by inversion of the chordal measurements and simulations shown in Fig. 1.

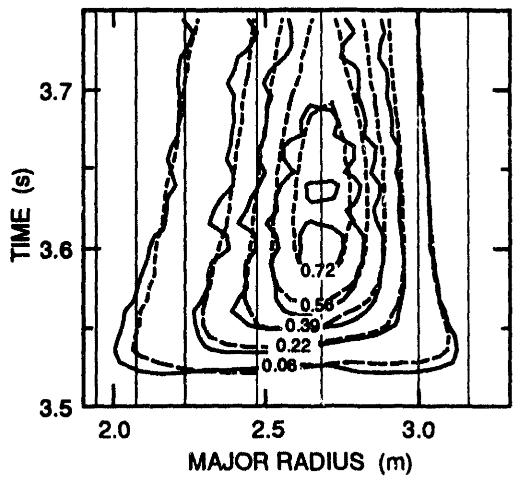

Fig. 3. Contour plots of 14.1 MeV neutron volume emission rate, obtained by Abel inversion of chord-integrated measurements (solid lines) and TRANSP simulations (dashed lines). Contours are labeled with fractions of maximum values. Thin vertical lines represent positions of chords.

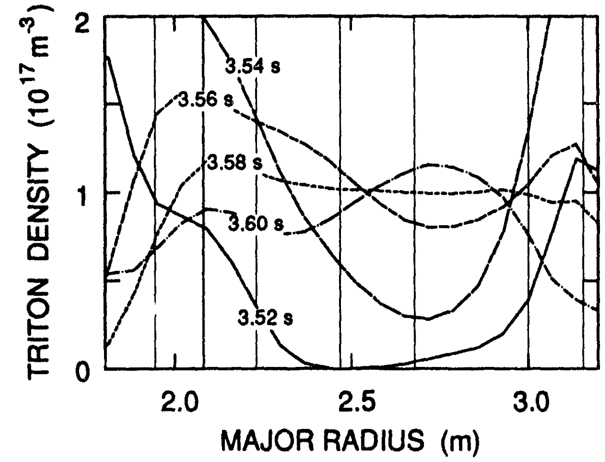

Fig. 4. Radial profiles of triton density at 20 ms intervals after injecting a pure tritium gas puff into a neutral beam heated deuterium supershot. Curve labels represent time from the start of the discharge. Gas was injected at 3.5 s. Thin vertical lines represent positions of measurement chords.

Triton Density

The local emissivity of $t(d,n)\alpha$ neutrons is related to the local triton and deuteron densities by the expression $s_n = n_t n_d \langle\sigma v\rangle$, where n_d denotes the total deuteron density, including fast ions from the injected neutral beams, and the cross section is averaged over all relative velocities. We have made use of a TRANSP simulation to evaluate $n_d \langle\sigma v\rangle$ and extract triton densities from neutron emissivities. In the simulation, the triton density was assumed to be constant in space and time (5×10^{17} m^{-3}), and the 14.1 MeV neutron emission along each measurement chord was computed, using measured values for other plasma parameters. The calculated chordal values were then Abel inverted and compared with values from Fig. 2. This method properly takes into account ion velocity distribution functions and fast ion drift orbit shifts. Resulting profiles are shown in Figs. 4 and 5.

Figure 4 illustrates the rapid temporal evolution of the triton density profile, from a cylindrical shell immediately after the gas puff to a flat profile in about 80 ms. The profile then becomes slightly peaked on axis and, as illustrated in Fig. 5, gradually decays in magnitude with little additional change in shape. Positions of the measurement chords are represented by thin vertical lines in Figs. 4 and 5. For comparison with the asymptotic triton density profile shape, the dotted curve in Fig. 5 shows the electron density profile. Because of the limited number of measurement chords, it is not possible to resolve any fine structure which might exist near the axis in the triton density profiles .

Analysis of the density profiles is presently underway to evaluate tritium transport coefficients.

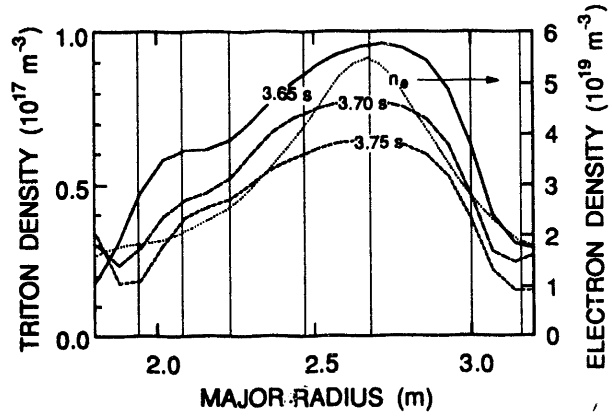

Fig. 5. Radial profiles of triton density at 50 ms intervals after injecting a pure tritium gas puff into a neutral beam heated deuterium supershot. Curve labels represent time from the start of the discharge. Gas was injected at 3.5 s. The dotted curve shows the electron density radial profile, with its scale on the right. Thin vertical lines represent positions of measurement chords.

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