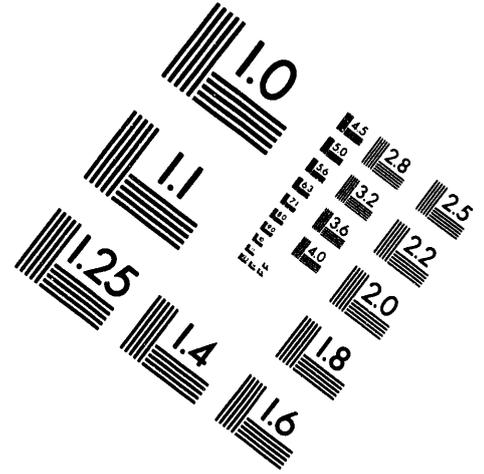
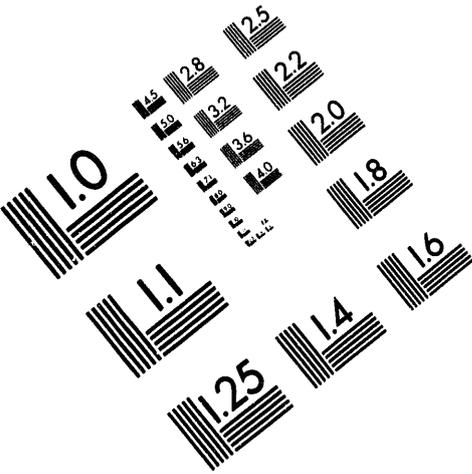




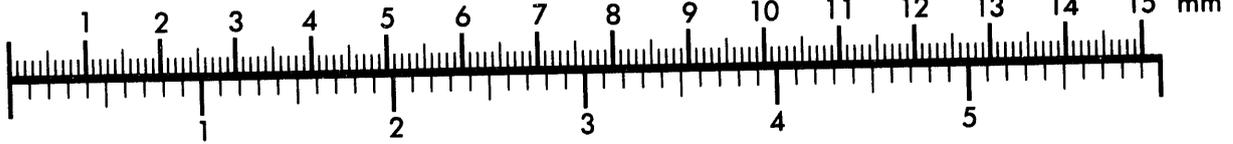
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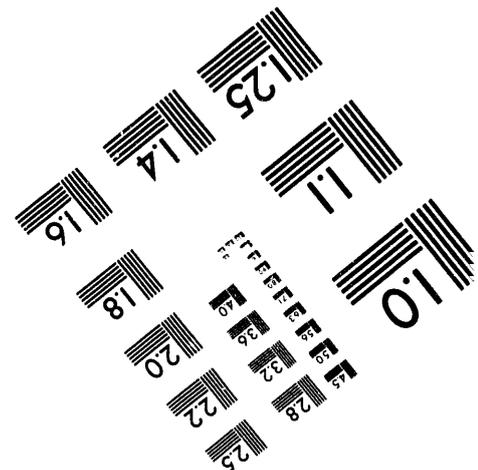
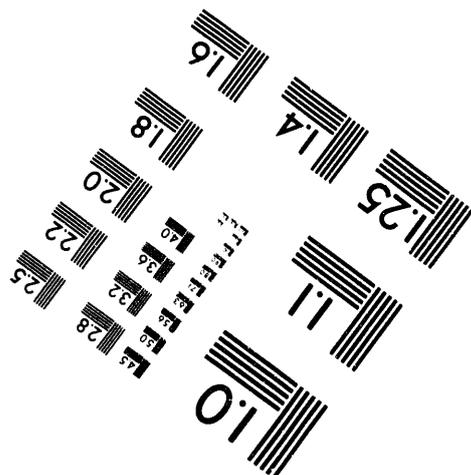
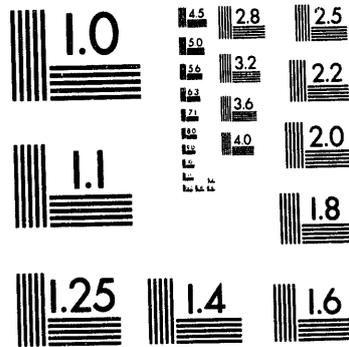
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# Observation of Doppler-Shifted $T\alpha$ Emission from TFTR Tritium Neutral Beams

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## ABSTRACT

195 tritium ion source shots were injected into TFTR high power plasmas during December 1993-March 1994. In addition, four highly diagnosed pulses were fired into the calorimeter. Analysis of the Doppler-shifted  $T\alpha$  emission of the beam in the neutralizer has revealed that the extracted ion composition for deuterium and tritium are indistinguishable:  $0.72 \pm 0.04 D^+$ ,  $0.22 \pm 0.02 D_2^+$ ,  $0.07 \pm 0.01 D_3^+$  compared to  $0.72 \pm 0.04 T^+$ ,  $0.23 \pm 0.02 T_2^+$ ,  $0.05 \pm 0.01 T_3^+$ . The resultant tritium full-energy neutral fraction is higher than for deuterium due the increased neutralization efficiency at lower velocity. To conserve tritium, it was used only for injection and a few calorimeter test shots, never for ion source conditioning. When used, the gas species was switched to tritium only for the shot in question. This resulted in an approximately 2% deuterium contamination of the tritium beam and vice versa for the first deuterium pulse following tritium. Data from the calorimeter shots indicates that tritium contamination of the deuterium beam cleans up in 5-6 beam pulses, and is reduced to immeasurable quantities prior to deuterium beam injection.

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## I. INTRODUCTION

Two of the world's large tokamaks, the Tokamak Fusion Test Reactor, TFTR, and the Joint European Torus, JET, have commenced deuterium-tritium operation in an effort to produce significant quantities of fusion power and to study the effect of alpha particles on hot plasmas.<sup>1, 2, 3</sup> To support tritium operation, the neutral beam systems on both devices were modified.<sup>4, 5</sup> Chief among these was the installation of grounded, neutralizer-based gas injection systems.<sup>5, 6</sup> Locating the gas systems in the neutralizer eliminates the need for an insulating break in the gas feed line, as required for injecting gas directly into the high voltage ion source, and enables the control electronics to be at ground potential. Each TFTR ion source presently has independent deuterium and tritium gas injection systems, a prototype of which has been previously tested.<sup>7</sup>

During tritium operation, TFTR ion sources are maintained in condition by injecting 50 ms deuterium pulses into the armor tiles of the tokamak every 150 s. To support tritium injection, the tritium gas system is enabled for one pulse. Previous tests of isotope exchange, using deuterium following hydrogen operation, revealed an unshifted H $\alpha$  intensity amounting to ~5% of the unshifted D $\alpha$  intensity.<sup>8</sup> These tests proved that deuterium ion source operation was not influenced by the presence of any lingering hydrogen, but provided no quantitative measure of the level of contamination.

Prior to tritium injection into TFTR plasmas, four tritium pulses were taken onto the internal calorimeter. These pulses were used to determine power supply setpoints, beam species, and power. Isotope exchange was also studied under a variety of conditions: 1.5 s 80 kW arc discharges and 0.5 s beam extraction.

Isotope exchange was observed at JET using the drive-in target neutron signal during hydrogen cleanup of deuterium. The contamination level reduced by a factor of two with the extraction of  $\sim 100$  C of deuterium ions; most ( $>95\%$ ) of the adsorbed gas could be removed by filament degassing.<sup>5</sup>

## II. DATA ANALYSIS

Beam composition is determined using an online computer code developed at the Lawrence Berkeley Laboratory (LBL),<sup>9</sup> and by manual offline analysis. Figure 1 is a spectrum of a 100 keV tritium beam. Left to right, the large lines are Doppler-shifted  $T\alpha$  emission from  $T(E)$ ,  $T(E/2)$ , and  $T(E/3)$ , and unshifted  $T\alpha$  emission from excitation of the thermal neutralizer gas (peaking at 50,000 counts). The extracted ionic species fractions are computed from a least squares determination of the areas under the Doppler-shifted peaks and subsequent application of beam neutralization rates and Balmer  $\alpha$  excitation cross-sections.<sup>10, 11</sup> Reflections<sup>12</sup> inside the copper neutralizer affect the online least squares fitting routine. As a result, all of the fits presented are trial and error least square fits. Lorentzians were used to fit the deuterium peaks, whereas the sum of two Gaussians were used to fit the tritium (the different treatments is due to tritium's off-perveance operation, and the resultant broader line widths). Areas affected by reflections are excluded from the fit.

When an ion source is operated on a mixed gas feed, many beam constituents are possible.<sup>13</sup> For deuterium mixed with tritium, the extracted constituents are:  $T^+$ ,  $T_2^+$ ,  $T_3^+$ ,  $D^+$ ,  $DT^+$ ,  $D_2^+$ ,  $D_2T^+$ ,  $T_2D^+$ , and  $D_3^+$ . For trace deuterium in a tritium beam,  $T^+$ ,  $T_2^+$ , and  $T_3^+$  are the primary species,  $D^+$ ,  $DT^+$ , and  $T_2D^+$  are secondary species, with  $D_2^+$ ,  $D_2T^+$ , and  $D_3^+$  being immeasurable. Table 1 gives the Doppler-shifts of the neutral daughters relative to  $T(E)$ . Figure 1 shows the location of the

secondary atoms. The 0.6 Å isotopic shift of  $D\alpha$  relative to  $T\alpha$  is insufficient to resolve the equi-velocity  $D(2E/5)/T(3E/5)$  and  $D(E/4)/T(3E/8)$  pairs or the unshifted  $T\alpha$  and  $D\alpha$ .

For trace tritium in deuterium,  $T_2^+$ ,  $T_2D^+$ , and  $T_3^+$  are ignorable. The Doppler-shifts for this case are also included in Table 1. Figure 2 is a typical tritium-contaminated deuterium spectrum showing the location of the emissions of the primary and secondary constituents.

Cleanup of tritium in deuterium was measured during the sequences following each of the four tritium pulses into the calorimeter; that is, after: 1) four deuterium arc pulses, 2) five deuterium arc pulses, and during each of 3) three, and 4) ten consecutive deuterium beam pulses. One difficulty was that the ion source used during these tests had reflections polluting the spectrum in the vicinity of the contaminant lines. Fortunately, clean deuterium spectra were available for subtraction. This background was reproducible to within 1% out of 1000 counts, or  $\sim 1/3$  of the statistical fluctuation level. Still, the background subtraction was the major contributor to the error bars.

It was not possible to measure the cleanup of deuterium in tritium since all tritium shots are followed by deuterium pulses. However, it was possible to estimate the deuterium content of the tritium beam pulses. The error bars for this calculation were greater than for the measurement of tritium in deuterium, since there was no clean tritium beam data to use as a reference.

For deuterium operation, the intensities of the contaminant lines were determined by subtracting a tritium-free spectrum from the raw data. For tritium, the background under the contaminant lines was interpolated. A thick neutralizer model was used in both cases to compute the extracted ion beam composition.<sup>14</sup>

### III. RESULTS

For operation at 100 kV, the tritium beam species was  $0.72 \pm 0.04 T^+$ ,  $0.23 \pm 0.02 T_2^+$ , and  $0.05 \pm 0.01 T_3^+$  compared to  $0.72 \pm 0.04 D^+$ ,  $0.22 \pm 0.02 D_2^+$ , and  $0.07 \pm 0.01 D_3^+$  for a pure deuterium beam.

In the sequence of 10 beam shots, the spectrum for the first deuterium pulse following one of tritium is presented in figure 2. Also shown is the clean reference spectrum used for subtraction. A beam composition of  $0.73 D^+$ ,  $0.22 D_2^+$ ,  $0.035 D_3^+$ ,  $0.014 T^+$ ,  $0.007 DT^+$ , and  $0.002 D_2T^+$  was found for this pulse. Of the total neutral power delivered to the calorimeter, the tritium fraction is 2.2%. Results from the four cleanup sequences are given in Table 2. Beam conditioning reduces the tritium content to negligible levels prior to any deuterium injection following a tritium pulse.

For deuterium in a tritium beam, the resultant beam composition is  $0.73 T^+$ ,  $0.22 T_2^+$ ,  $0.04 T_3^+$ ,  $0.013 D^+$ ,  $0.004 DT^+$ , and  $< 0.001 T_2D^+$ . Error bars on secondary constituents are  $\pm 25\%$ , the same as for the primary  $T_3^+$  above.

### IV. DISCUSSION

A portion of the deuterium in the tritium beams arises due to its presence in the gas feedstock.<sup>15</sup> Our inability to repetitively fire tritium beams until the deuterium is undetectable prevents us from ascertaining the extent of the feedstock contamination. The majority of the contamination is due to adsorption, and/or implantation into ion source surfaces during previous operation. Such is certainly the source of the tritium that contaminates the deuterium beams.

### ACKNOWLEDGEMENTS

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**TABLE 1.** Doppler-shifts of the primary and secondary atoms for a deuterium contaminated tritium beam and a tritium contaminated deuterium beam. The atom's energies are in parentheses.

<u>parent ion</u>	<u>D<sub>2</sub> in T<sub>2</sub></u>		<u>T<sub>2</sub> in D<sub>2</sub></u>	
	<u>daughter atom</u>	<u>Doppler-shift</u>	<u>daughter atom</u>	<u>Doppler-shift</u>
T <sup>+</sup>	T(E)	1	T(E)	0.816
D <sup>+</sup>	D(E)	1.225	D(E)	1
T <sub>2</sub> <sup>+</sup>	T(E/2)	0.707		
DT <sup>+</sup>	T(3E/5)	0.775	D(2E/5)	0.632
DT <sup>+</sup>	D(2E/5)	0.775	T(3E/5)	0.632
D <sub>2</sub> <sup>+</sup>			D(E/2)	0.707
T <sub>3</sub> <sup>+</sup>	T(E/3)	0.577		
T <sub>2</sub> D <sup>+</sup>	T(3E/8)	0.612		
T <sub>2</sub> D <sup>+</sup>	D(E/4)	0.612		
D <sub>2</sub> T <sup>+</sup>			D(2E/7)	0.535
D <sub>2</sub> T <sup>+</sup>			T(3E/7)	0.535
D <sub>3</sub> <sup>+</sup>			D(E/3)	0.577

**TABLE 2.** Tritium neutral power fraction of deuterium beams following arc and deuterium beam extraction. Error bars are  $\pm 0.002$ .

<u>number of</u> <u>pulses</u>	<u>type of cleanup pulses</u>			
	<u>arc</u>	<u>arc</u>	<u>beam</u>	<u>beam</u>
1			0.025	0.022
2			0.010	0.009
3			0.003	0.006
4	0.010			0.004
5		0.006		0.003
6				0.001
7				0.002

**Figure Captions**

Figure 1. Doppler-shifted  $T\alpha$  spectrum of a tritium beam from a 500 channel Optical Multi-channel Analyzer. The locations of the emissions of the atoms in Table 1 are indicated.

Figure 2. A Doppler-shifted  $D\alpha$  spectrum of the full-, half-, and third-energy components of a tritium contaminated deuterium beam. The locations of the emissions of the atoms in Table 1 are indicated. Also shown is the spectrum of an uncontaminated deuterium beam.

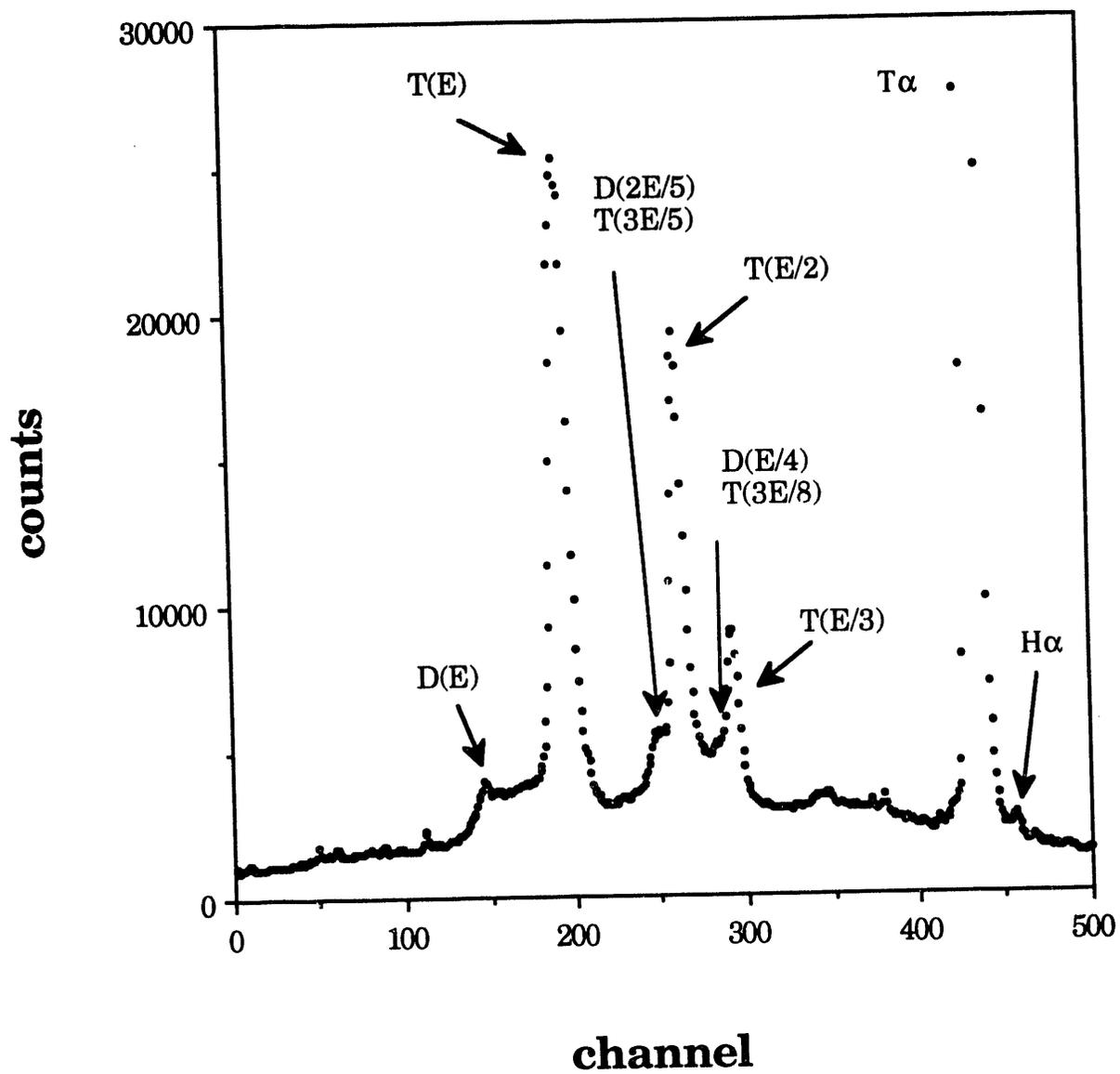


Fig. 1

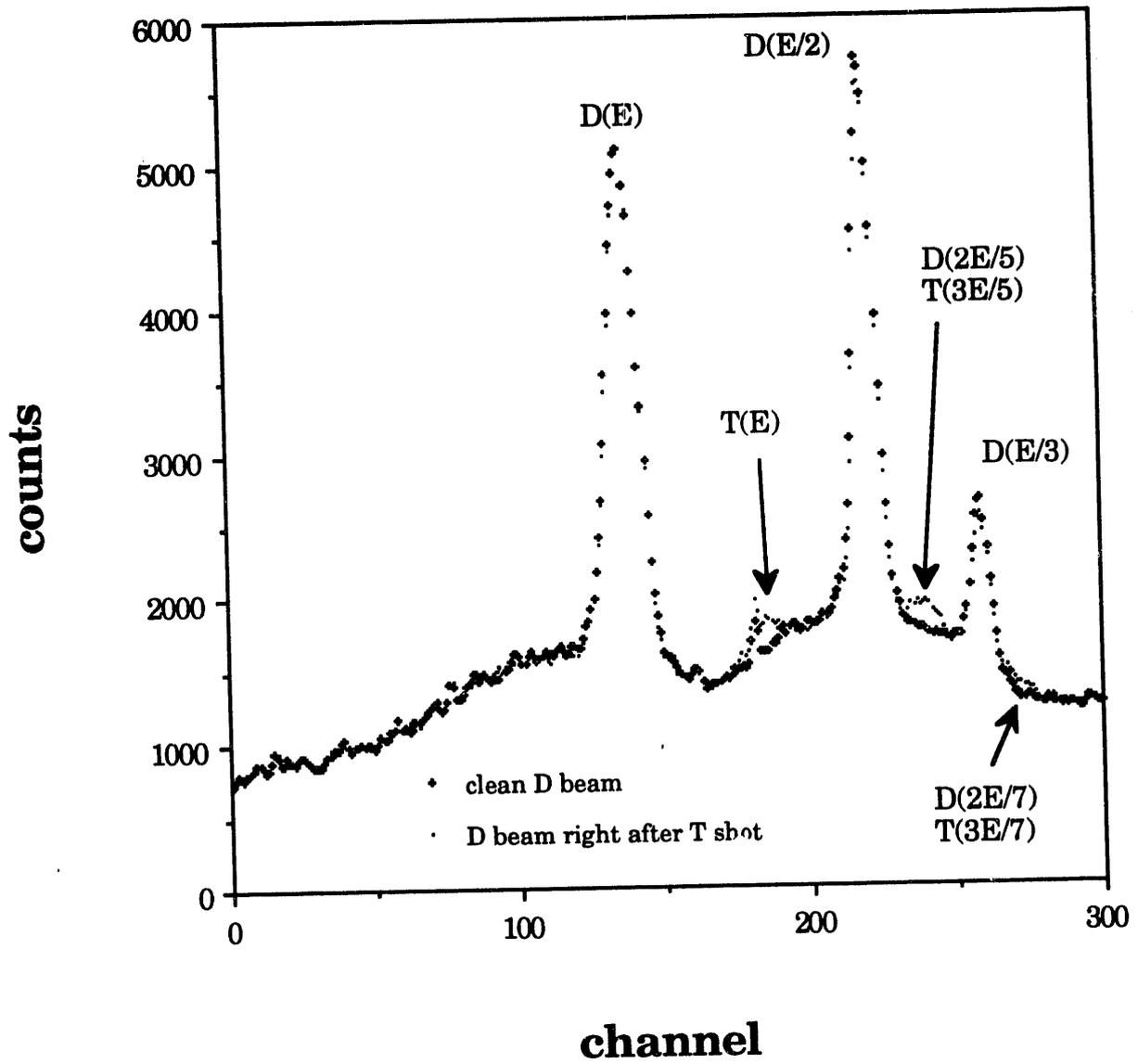


Fig. 2

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