JOINT EUROPEAN TORUS

JET–P(89)24

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** See Appendix 1*

Preprint of Paper to be submitted for publication in
Review of Scientific Instruments

HDF/ms-mw-hs/C / 5.4.89 / HDF-LRG(2)

EXTRACTED BEAM COMPOSITION WITH A MIXED ISOTOPE FEED

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ABSTRACT

Both the Tokamak Fusion Test Reactor and the Joint European Torus, two large magnetic confinement fusion devices, will use high powered tritium beams. The suggestion has been made that tritium consumption could be reduced if tritium is only fed into the plasma source and deuterium or hydrogen is used as neutralisation target by operating with deuterium fed independently into the neutralizer. We report on measurements we performed with deuterium and hydrogen and of the beam contamination that occurs in such an operating mode.

I. INTRODUCTION

In the present generation of magnetic confinement research devices, there are two - both tokamaks - that will operate with deuterium tritium plasmas in the final phase. These machines are the Tokamak Fusion Test Reactor (TFTR) at Princeton and the Joint European Torus (JET) in the U.K. 20 MW of the plasma heating in JET and 30 MW on TFTR is supplied by neutral (deuterium) beam injection. In the D-T phase, half of the beam systems on each tokamak will be required to produce tritium beams (the other half remaining deuterium).

The injection systems basically consist of a plasma source from which a beam of positive ions is extracted and accelerated, followed by a gas cell (neutralizer) where a fraction of the beam ions are converted to neutrals atoms by electron capture. The ion fraction is then magnetically separated from the neutrals and dumped onto water cooled plates.

Differing restrictions upon the allowed tritium inventory imposes constraints upon neutral beam operating scenarios for both machines.

One way to reduce the tritium consumption would be to use hydrogen or deuterium in the neutralizer while tritium is only fed into the plasma source as suggested by Kamperschroer [1].

Operation with deuterium in the neutralizer for tritium injection would only be highly attractive if it allowed a major reduction in tritium consumption per amp of neutral tritium beam produced, while at the same time not contaminating the beam with significant amounts of deuterium, since significant admixtures of different isotopes would be undesirable for several reasons. In this mixed isotope regime, the current required for minimum beam divergence (optimum perveance) would vary with the isotope mix of the ion beam, which is likely to change with the relative amounts of gas being contributed by the deuterium and tritium feeds. This would render source operation more complex.

Furthermore, a tritium beam contaminated with deuterium would consist of ions accelerated as D^+, T^+, and all possible mixtures of the di- and tri-atomic molecular ions of the two isotopes $D_mT_n^+$ (m,n = 0,1,2,3 and m + n <3). These molecular ions will be broken up in the neutralizer resulting in ions with differing momenta depending upon the mass of the original molecule. All of these ions must be deflected by the beamline deflection magnet in such a way that their power is deposited safely on the dumps which have originally been designed for a beam containing ions of only three different momenta. The complications caused by the contamination of the beam would be even more pronounced if hydrogen (protium) were used in the neutralizer because of the even greater spread in momenta.

Contamination of the beam is to be expected if the gas flow between the neutralizer and the source is in, or near, the free molecular flow regime. However, it is not obvious how to quantify this contamination. There is experimental evidence that the gas temperature in the plasma source is considerably above ambient [2] and in the neutralizer an anomalous reduction of the gas density, presumed to be caused by beam-gas collisions, has been observed in both the JET and TFTR neutralizers [3], [4]. The uncertainty in calculating the contamination of the source gas led to the experiments reported here which, to our knowledge, for the first time have examined the effects of operating a neutral beam system with different isotopes in the plasma source and in the neutralizer.

II. EXPERIMENTAL SET-UP

These experiments were performed on the JET neutral beam test bed. Since the JET neutral beam test bed is not tritium compatible (there are no tritium compatible facilities anywhere suitable for tests of fusion-relevant ion sources), deuterium and hydrogen were used rather than tritium and deuterium.

The JET test bed differs in many details from a TFTR beamline, however, for the purposes of this experiment it is quite similar. A JET ion source (fig. 2) is followed by the neutralizer duct (actually two connected sections). From there the extracted beam traverses the neutraliser, then a large vacuum tank (NIB) into a target tank. The test bed beam dump, which is located in the target tank, is designed to take the full power of the combined ion and neutral beams which allows operation without the bending magnet shown in Fig. 2, thus avoiding the complication of dumping all the different momentum components on the ion dumps. The neutralizer gas was fed at the junction of the two neutralizer sections, about halfway down the total length of the neutralizer.

In the target tank, a modified Jarrell-Ash spectrometer measured the Doppler-shifted light from excited beam particles to obtain the contributions of the various velocity components. A neutron detector outside the target tank near the beam dump was used to obtain a qualitative measure of the D-D neutron production rate. All the experiments reported were carried out at an acceleration potential of 100 kV.

III. EXPERIMENTAL RESULTS

The Jarrell-Ash spectrometer was modified to have a rotating mirror which allowed 8-9 spectrum scans to be obtained during 3.5 second beam pulse. Figure 3 shows one of these spectra taken during a beam pulse with a flow of about 11.7 mbar-litres/sec of hydrogen into the source and about 43 mbar-litres/sec of deuterium into the neutralizer. In order to obtain the beam composition this raw data is to be weighted by the Jarrell-Ash sensitivity curve (which was centred approximately halfway between the two peaks to the right) and by the velocity dependence of the excitation cross sections. The separate peaks in each complete scan were then summed and averaged over the duration of each beam pulse. Spectral scans which were interrupted by electrical breakdowns in the accelerator were deleted.

The identities of the peaks in figure 3 are given in its caption. Of note is the fact that there are so many peaks, indicating substantial contamination of the beam by the neutralizer isotope. The peaks correspond to the various breakup products from the possible molecular masses. For example, deuterium at 2/5 of the acceleration energy (indicated as D [2E/5]) comes from the breakup of DDH^+, H[E/4] comes from HHD^+ etc. If deuterium and tritium were used instead of deuterium and hydrogen, there would be even more peaks, since the velocity degeneracy which causes some of these peaks to lie on top of each other (such as the quarter energy hydrogen and the half energy deuterium) would be broken. Clearly this large number of momentum components would make it very difficult to position the residual ions on the dumps, and would almost certainly require modifications of the dump geometry.

In deducing the isotope mix of the beam, only the amplitudes of the two most shifted peaks are needed (those on the right in fig. 3), which correspond to the full energy hydrogen peak (from H^+) and the overlapped peak due to full energy deuterium (from D^+) and half energy hydrogen (from the breakup of HH^+). Assuming that the relative amounts of atomic and molecular ionic species produced in the source are the same as for normal operation with a single isotope (an assumption which should not cause any large error), we can subtract the half energy hydrogen contribution from the second-most shifted peak to arrive at the relative amplitudes of the full energy H and D peaks. If it is assumed that these are proportional to the total amount of H and D in the beam under these conditions, the isotopic composition of the beam can then be deduced. This last assumption presumes that the species mixes of the two isotopes are similar in the D-H plasma, which may not be precisely correct, but again should not introduce a large error.

Figure 4 illustrates the isotopic composition deduced for the beam as a function of hydrogen flow into the neutralizer while the source deuterium feed is held constant at 8.3 mbar litres/sec. The data points are the measured values, while the curve was calculated assuming that the gas was in the free molecular flow regime (i.e. no viscous or momentum transfer effects) and that the relative currents extracted from

the source plasma were proportional to $1/\sqrt{m}$, where m is the mass of the ion being extracted (the ions are all singly charged). From

fig. 4 it can be seen that this model gives reasonably good agreement with the data over a wide range of neutralizer gas feed flows. Earlier measurements, using an 80 kV JET PINI show a similar result (fig. 5), however, the fit is better without a mass dependence. The small difference can be explained by the errors in the conductances used for the calculations.

Figure 6 shows the measured neutron counts during an experiment where hydrogen was fed into the ion source at a constant rate of 11.7 mbar litres/sec while starting at zero and increasing the flow of deuterium into the neutralizer over a number of shots. The fact that large amounts of neutrons are produced is indicative of beam contamination. Figure 6 is only intended as a qualitative indication of deuterium in the beam, as uncertainties arise from the high dead time in the electronics used, the unknown fraction of the neutrons from reactions in the neutraliser as opposed to those at the beam dump, and the fact that the amount of deuterium implanted in the beam dump was probably varying. These factors all serve to distort the amplitude and shape of the resulting neutron yield curve. Nonetheless, we can calculate the expected neutron yield assuming that the gas flow between the neutralizer and the source is simply free molecular, with a $1/\sqrt{m}$ dependence in the extracted beam, and that the deuterium target density in the beam dump is constant. If we then normalize the calculations to the measured count rate for the data point at the maximum D_2 flow rate, we obtain the curve shown in figure 6. The predicted shape of the yield curve appears to be in reasonable agreement with the dependence of the data.

IV. DISCUSSION

We have for the first time operated a high power beam source with a different isotope fed to the source and neutralizer, and it has been found that the extent to which the neutralizer gas feed contaminates the resulting beam appears to be approximately consistent with that which would be predicted if gas flow along the neutralizer is in free molecular flow. The resulting contaminated beam appears to be difficult to use for fusion applications although using an alternative gas in the neutralizer could be more attractive in a system which has pumping between the source and the neutralizer. In the present JET and TFTR beamlines, where the source and neutralizer are closely coupled, it appears that tritium usage can more expediently be reduced by reducing the length of the gas and arc pulses that precede the start of the beam pulse, rather than by incurring the complications attendant upon a mixed isotope beam.

ACKNOWLEDGEMENTS

It is a pleasure to acknowledge useful discussions with Dr. E. Thompson and to thank the operations staff of the JET neutral beam test bed.

REFERENCES

[1] J. Kamperschroer, private communication (1987).

[2] T S Green, A J T Holmes. Measurements of neutralisation efficiency of a 50 KeV He^+ beam in a He gas cell. Rev Sci Instr 56(6) 1982 P816.

[3] R.Hemsworth et al. Neutralisation Measurements for the JET injector. Proc. 13th Conf. on Contr. Fus. and Plasma Heating, Schiersee, FDR, 1986, p 297.

[4] J. Kamperschroer, private communication (1987).

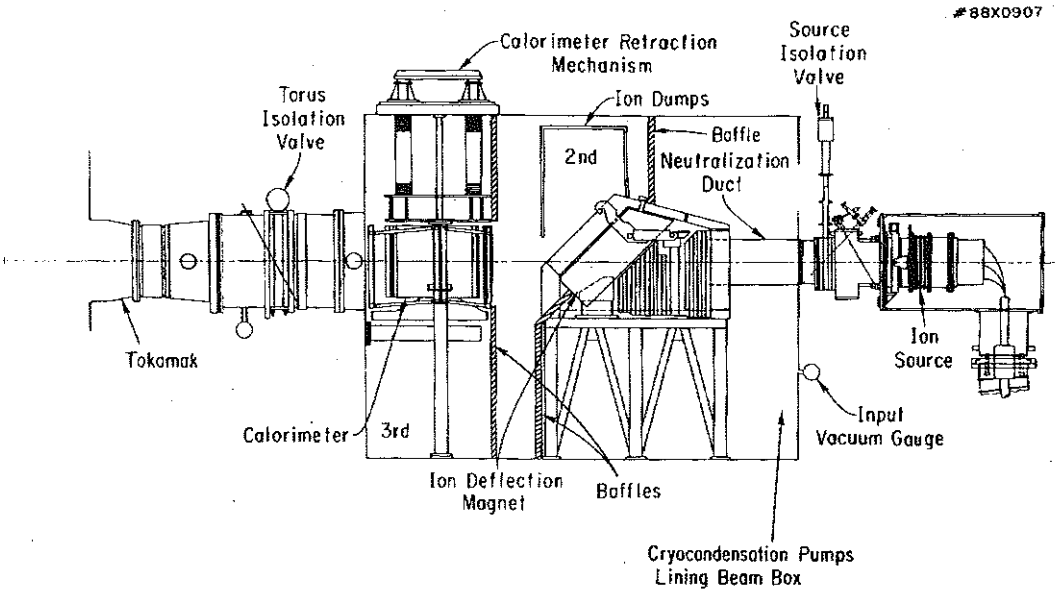


Fig. 1 Side view diagram (not to scale) of a TFTR beamline. Each beamline has three ion sources and corresponding beamline components arranged in a horizontal array.

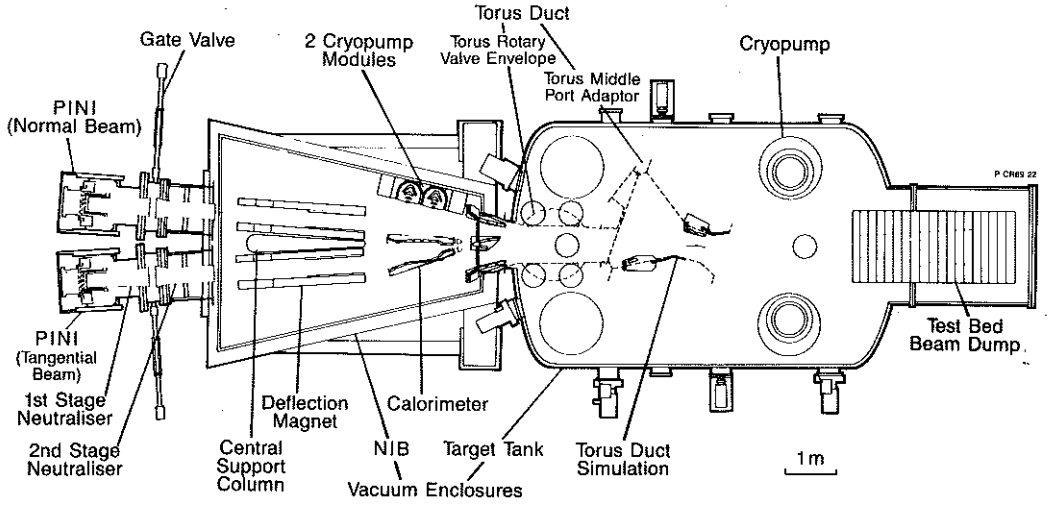


Fig. 2 Plan view of the JET Test Bed.

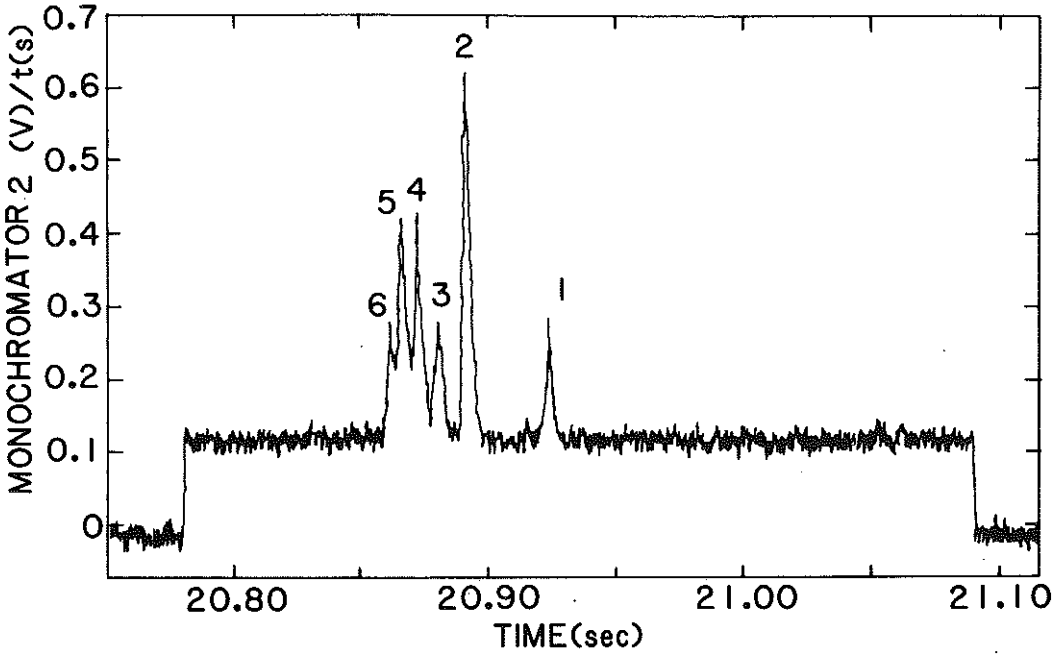


Fig. 3 One sweep of the Doppler shifted spectrum during operation at 100 kV with 8.3 mbar litres/sec flow of D_2 into the source and 43 mbar litres/sec flow of H_2 approximately halfway down the neutralizer. As one moves to the right, the peaks are progressively more Doppler shifted, corresponding to higher velocities. The peaks are composed of light from the following beam components: pk 1 is H [E], pk 2 is H [E/2 H_2^+] + D [E], pk 3 is H [E/3 H_3^+], pk 4 is H [E/4 H_2D^+] + D [E/2 D_2^+], pk 5 is H [E/5] + d [2E/5], and pk 6 is D [E/3].

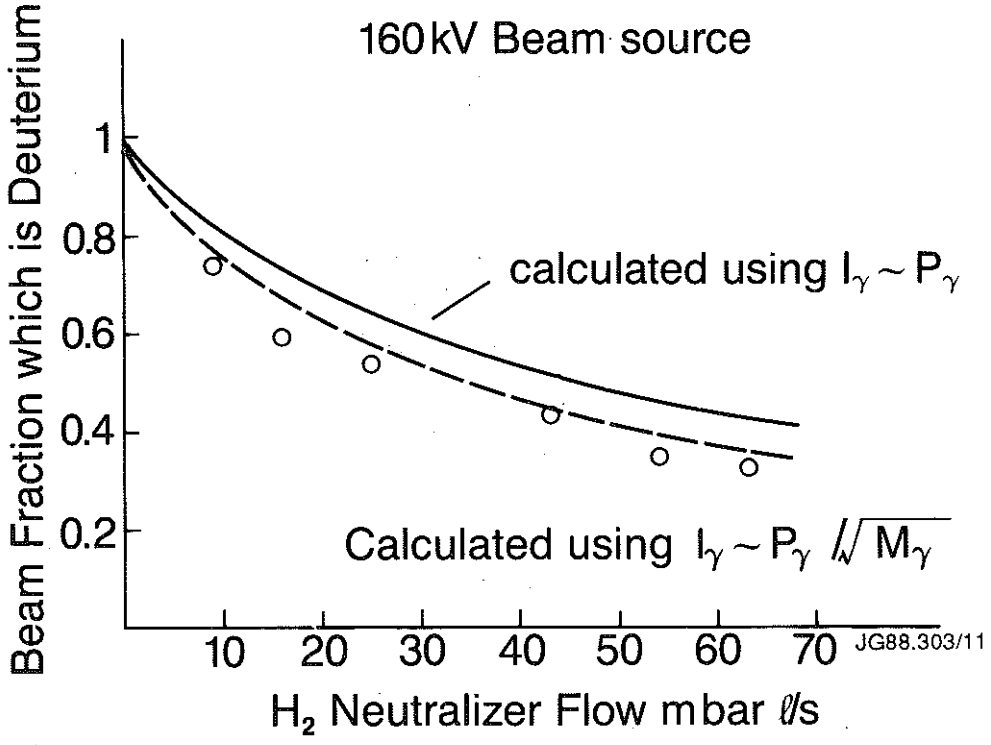
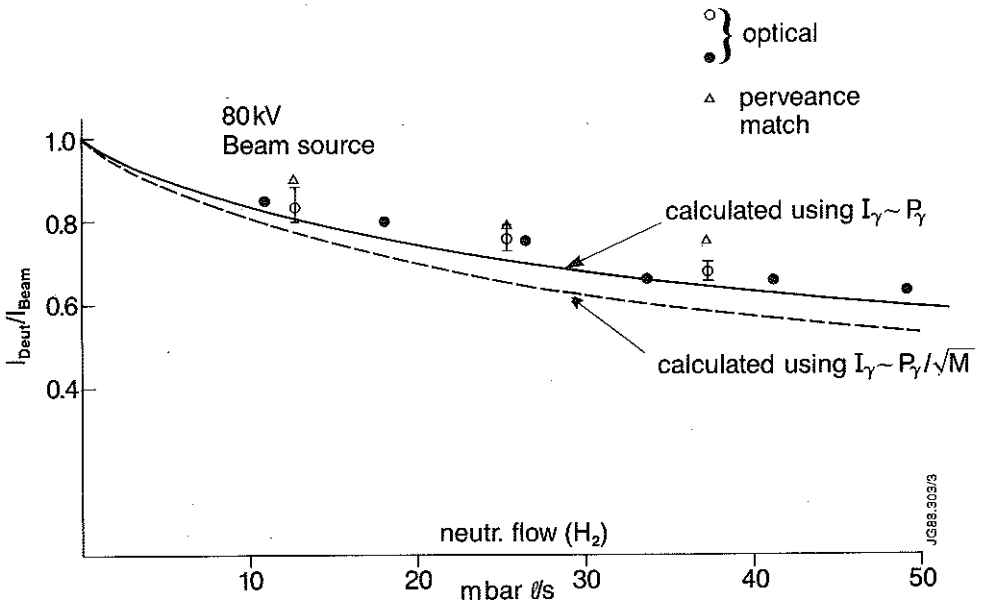


Fig. 4 Fraction of extracted beam composed of deuterium as the neutralizer hydrogen flow is varied while the source flow is held at 8.3 mbar litres/sec during 100 kV operation. The calculated curve is for free molecular flow with an inverse square root mass dependence in the extracted beam.



Measured isotopic mix in the extracted beam for 10.5 mbar ℓ/s deuterium into the source for 36 Amps of extracted current versus flow (H_2) into the neutraliser. I_γ and P_γ are the extracted current and the partial pressure in the plasma source for the hydrogen isotope with the mass M_γ.

Fig. 5 As 4 but with an 80 kV JET beam source

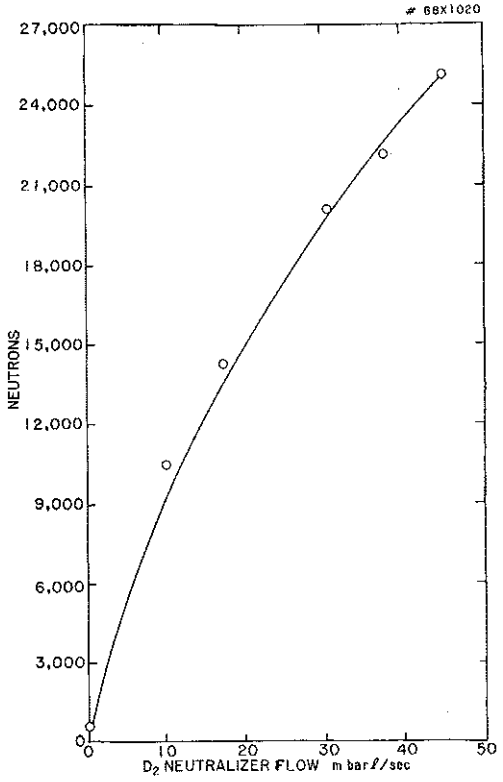


Fig. 6 Neutron signal (normalized for current and pulse length) as a function of D_2 feed halfway down the neutralizer while the source, the calculated flow is for free molecular flow with an inverse square root mass temperature in the extracted beam. It has been normalized to the data point at 45 mbar/sec.

APPENDIX 1.

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