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USE OF THE TFTR PROTOTYPE CHARGE EXCHANGE NEUTRAL ANALYZER FOR FAST He_3^{++} DIAGNOSTICS DURING ICRF HEATING ON PLT

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Use of the TFTR Prototype Charge Exchange Neutral Analyzer For Fast He_3^{++} Diagnostics During ICRF Heating on PLT

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ABSTRACT

The Charge Exchange Neutral Analyzer (CENA) for TFTR is designed to measure singly charged ion species of atomic mass A = 1, 2, and 3 simultaneously with up to 75 energy channels per mass and an energy range of $0.5 \lesssim AE \lesssim 600$, where AE is in units of AMU·keV. Plans to test the prototype analyzer on PLT prior to installation on TFTR are discussed. The capability of the analyzer to simultaneously measure singly reionized H, D, and He_3 charge exchange neutrals makes the analyzer of particular interest for recently proposed fast He_3^{++} diagnostics during ICRF heating on PLT.

1.0 INTRODUCTION

A technique for measuring the fast He_3^{++} energy distribution during ICRF heating on PLT was recently proposed.[1] In one approach, the technique would require conversion of the South counter PLT heating beam to a He_4^0 doping beam to induce double charge exchange of He_3^{++} minority ion species. Viability of this approach requires upgrading of the horizontal FIDE charge exchange diagnostic to provide mass analysis capability. This paper proposes to provide such capability by replacing the existing horizontal analyzer on PLT with the prototype E||B analyzer[2] being developed for the TFTR charge exchange systems.

2.0 E||B CHARGE EXCHANGE ANALYZER

Since the operation of the TFTR prototype analyzer has been discussed in detail elsewhere,[3-4] only a description of the salient features is presented in this report. The schematic in Fig. 1 shows plan and elevation cross sections of the analyzer with the insert showing the configuration of the detector.

The analyzer uses a semicircular region of parallel electric and magnetic fields to cause separation of incoming H^+, D^+, and T^+ (He_3^+) ions into linear mass columns, each containing the energy dispersed ions of a given charge-to-mass ratio, as illustrated in Fig. 2. The detector is a large area (4.6 cm x 38 cm) chevron microchannel plate. The detector elements of the plate are arrayed in three columns, one for each mass specie. Each mass column is divided into 75 anode pads of dimension 0.4 cm wide by 1.6 cm in height. This arrangement enables simultaneous measurement of 75 energy channels for each of three mass species with an energy resolution which varies from 0.8-4.0% depending on the anode pad location in a mass column.

Up to 225 signal channels each will be provided with pulse counting electronics, including 12-bit, 10 MHz scalars and local memory. Control of the diagnostic devices and data acquisition/analysis will be interfaced with the CICADA system.

The prototype E||B analyzer is currently under calibration in the CICADA-interfaced Charge Exchange Laboratory (CXLAB). Figure 3 shows the analyzer (foreground) and the 150 keV - 300 μA General Ionex ion beam source to be used for calibration of the analyzer using H^+, H_2^+, H_3^+, and helium particle beams.

3.0 EXPERIMENTAL ARRANGEMENT

The plan schematic of PLT given in Fig. 4 shows the location of the present horizontally scanning Fast Ion Diagnostic Experiment (FIDE). The FIDE analyzer provides energy, but not mass, resolution and has a field of view which extends from perpendicular to about 10 cm outboard of the 134 cm plasma major radius. Replacement of the existing analyzer with the prototype E||B analyzer would provide the following advantages:

1) Both mass and energy resolution capability.
2) An equal or perhaps increased angular scanning range due to smaller dimension (9 inches) of the E||B analyzer in the toroidal direction.
3) A flexible test-bed for evaluation of the E||B analyzer operation prior to installation on the TFTR.

Typical FIDE operation involves data acquisition simultaneously along four sightlines with accumulation of multiple shots usually required to build up the desired energy spectrum. On the other hand, the E||B analyzer is expected

to acquire the complete energy spectrum for each ion species in a single shot, but multiple shots are required in order for the single sightline to cover an equivalent viewing field. As a result, roughly the same number of discharges is needed to acquire a given data set for either of the analyzers.

The proposed technique to measure the fast He_3^{++} ion distribution calls for conversion to helium operation of the PLT counter beam injector adjacent to the FIDE diagnostic (see Fig. 4). With this arrangement, the He_4^o beam would provide neutral doping in at least part of the viewing field of the FIDE analyzer, primarily for near perpendicular charge exchange measurements of the induced He_3^{++} double charge exchange neutral spectrum.

On the TFTR machine, the arrangement of the fast ion charge exchange analyzer and the diagnostic neutral beam was designed to provide doping throughout the analyzer viewing field. Figure 5 shows the TFTR doping beam in the full tangential position along with a subset of available analyzer sightlines. The beam can be steered remotely between the position shown and perpendicular to the torus. Conversion of the 80 keV-15A hydrogen/deuterium ion source to helium operation is expected to provide an experimental setup very favorable to performing He_3^{++} fast ion diagnostics during proposed ICRF heating on the TFTR.

4.0 ESTIMATE OF He_3 SIGNAL AMPLITUDE

An estimate of the count rate in a single detector channel of the E||B analyzer is derived in this section. The charge exchange production of He_3^o on the background neutral density is assumed to be negligible compared with that due to double charge exchange of He_3^{++} on the He_4^o doping beam neutral density given by

$$n_b = j/ev = 1.43 \times 10^{11} \frac{j}{(E_b/A_b)}^{1/2} \quad cm^{-3} \tag{1}$$

where $j(A/cm^2)$, $E_b(keV)$, $A_b(AMU)$ are the equivalent neutral current density, energy, and atomic mass number of the beam neutrals, respectively. The detector count rate due to beam doping can be approximated by

$$\Gamma = n_b \eta_{He} n_e f_{He}(E) \langle \sigma v \rangle K(E) \ell \tag{2}$$

where η_{He} is the fractional density of He_3^{++} in a plasma of density $ne(cm^{-3})$, $f_{He}(E)$ is the fast He_3^{++} ion energy distribution, $\langle \sigma v \rangle$ is the charge $He_3^{++} + He_4^{\circ} \rightarrow He_3^{\circ} + He_4^{++}$ charge exchange reaction rate, $K(E)$ is the analyzer response function, and $\ell(cm)$ is the path length through the doping beam measured along the sightline of the analyzer. In this approximation, attenuation effects are neglected for both incoming beam neutrals as well as emerging charge exchange neutrals.

The instrumental response function of the analyzer is given by

$$K(E) = A \cdot \frac{d\Omega}{4\pi} \cdot \frac{\Delta E}{E} \cdot E \cdot \xi \cdot \gamma \tag{3}$$

where

$$A \cdot \frac{d\Omega}{4\pi} = \frac{\pi}{4} \left(\frac{ar}{L}\right)^2 \tag{4}$$

and

$$\frac{\Delta E}{E} = \frac{\Delta Z \cdot B}{\sqrt{20.7AE}} \quad . \tag{5}$$

The quantities denoted by the symbols in Eqs. (3)-(5) are as follows:

- A = cross-sectional area of the viewed plasma region at distance, L, from the analyzer entrance aperture (cm^2),
- $d\Omega$ = solid angle subtended by the analyzer entrance aperture (steradians),
- ξ = stripping cell efficiency,
- γ = detector efficiency,
- $\Delta E/E$ = analyzer energy resolution,
- a = radius of the field-of-view limiting aperture (cm),
- r = radius of the stripping cell aperture (cm),
- L = distance between the stripping cell and field limiting apertures (cm),
- ΔZ = width of anode pad detector element (cm),
- B = analyzer magnetic field (kG),
- A = mass number (singly charged ion),

and

- E = ion energy (keV).

Using the following values for "fixed parameters" under envisoned PLT conditions,

$\gamma = 1.0$

$a \cong 2.5$ cm

$r = 0.15$ cm

$L = 200$ cm

$\Delta Z = 0.4$ cm,

Eq. (3) becomes

$$K(E) = 2.4 \times 10^{-7} \cdot B \cdot \left(\frac{E}{A}\right)^{1/2} \cdot \xi(E) \ . \qquad (6)$$

For the PLT charge exchange diagnostics, the stripping cell gas is usually He_4^o. In a helium cell, reionization of He_3^o involves the following reactions:

$$\begin{aligned} He_3^o + He_4^o &\rightarrow He_3^+ \\ He_3^o + He_4^o &\rightarrow He_3^{++} \\ He_3^+ + He_4^o &\rightarrow He_3^{++} \ . \end{aligned} \qquad (7)$$

The cross sections for these processes are shown in Fig. 6. As can be seen clearly, the cross sections favor production of He_3^+ over He_3^{++} by more than an order of magnitude over the energy range of interest (10-100 keV). The A = 3 mass channel, therefore, is expected to see singly ionized He_3^+ ions. The smaller component of He_3^{++} ions will be deflected below the He_3^+ mass

channel (see Fig. 2). Although interference with the D^+ mass channel is possible, the D^+ signal level in most cases will be considerably larger so that the He_3^{++} signal, if regarded as a contaminant, may not be detectable in practice. By comparison with the cross section for the process

$$H^o + He_4^o \rightarrow H^+ \qquad (8)$$

also shown in Fig. 5, it can be seen that the H^o and He_3^o reionization cross sections are comparable at the upper end of the energy range (~ 100 keV), but the He_3^o cross section becomes an order of magnitude smaller in the lower energy range (~ 10 keV) and continues to decrease sharply.

The equilibrium fractions for reionization of hydrogen and helium atomic beams in helium gas are shown in Fig. 7. The stripping efficiency for helium beams ranges from 0.04 at 10 keV to 0.30 at 100 KeV.

For diagnostics of helium charge exchange neutrals, H_2 provides a more suitable stripping cell gas. From the equilibrium fraction curves[5] given in Fig. 8, the stripping efficiency is seen to vary from ~ 0.15 at 10 keV to ~ 0.28 at 100 keV and is relatively flat over the energy range of interest. At 10 keV, the H_2 cell yields a gain of ~ 4 in efficiency compared with helium and at 4 keV the gain is about an order of magnitude[6]. For purposes of estimating the detector count rate, an H_2 stripping cell operated at one-fourth of equilibrium is assumed giving $\xi \sim 0.05$.

From the above considerations, the following parameters which apply for He_3^{++} at an energy of 50 keV are used in conjunction with Eqs. (1), (2), and (5) to estimate the detector count rate:

$j = 40\ mA/cm^2$

$E_b = 40\ keV$

$A_b = 4\ AMU$

$\eta_{He} = 0.05$

$n_e = 2 \times 10^{13}\ cm^{-3}$

$\sigma \cong 1.2 \times 10^{-16}\ cm^2$

$\ell = 20\ cm$

and $B = 3.0\ kG$

$\xi = 0.05$

which yields

$$K(E) = 3.6 \times 10^{-8} \left(\frac{E}{A}\right)^{1/2}.$$

The parameters used above do not vary appreciably over the energy range $10 \lesssim E \lesssim 100$ keV. Expressing the velocity term in the charge exchange reaction rate by

$$v = 4.36 \times 10^{7} \left[\frac{E\ (keV)}{A}\right]^{1/2} \tag{9}$$

where A = 3 is the atomic mass of He_3, Eq. (2) reduces to

$$\Gamma = 2.3 \times 10^{6}\ f_{He}(E)E \qquad sec^{-1}. \tag{10}$$

For typical He_3 minority ICRH conditions in PLT, the fast He_3 ion distribution exhibits calculated[7] central equilibrium values of

$$10^{-2} \lesssim f_{He}(E) \lesssim 10^{-3}$$

over the energy range

$$10 \leq E \leq 100 \text{ keV} ,$$

so that $f_{He}(E)E \sim 0.1$ which yields an estimated detector count rate of

$$\Gamma = 2.3 \times 10^{5} \text{ sec}^{-1}$$

relatively independent of energy in the 10-100 keV range. Thus with the use of He_4^o neutral beam doping, measurement of the fast He_3^{++} ion energy distribution with a time resolution of 1 ms appears feasible.

5.0 CONCLUSIONS

Installation of the TFTR prototype E||B analyzer on PLT in place of the existing FIDE device is proposed in order to test the new analyzer and to provide expanded charge exchange diagnostic capability, in particular, to enable measurement of the fast He_3^{++} spectrum during ICRF minority heating.

An estimate of the He_3^{+} detector count rate was made based on a calculation of the analyzer instrumental response function and use of a PLT neutral injector to provide He_4^{o} doping for the double charge exchange reaction with He_3^{++} ions. A simple but nevertheless reasonable estimate of necessary parameters yields a detector signal level of $\sim 2 \times 10^5$ counts per second per energy channel which exceeds the typical rate needed for 1 ms time resolution measurements.

Calibration of the prototype E||B analyzer is expected to be completed in time for installation on PLT in the fall of this year (1981).

ACKNOWLEDGMENT

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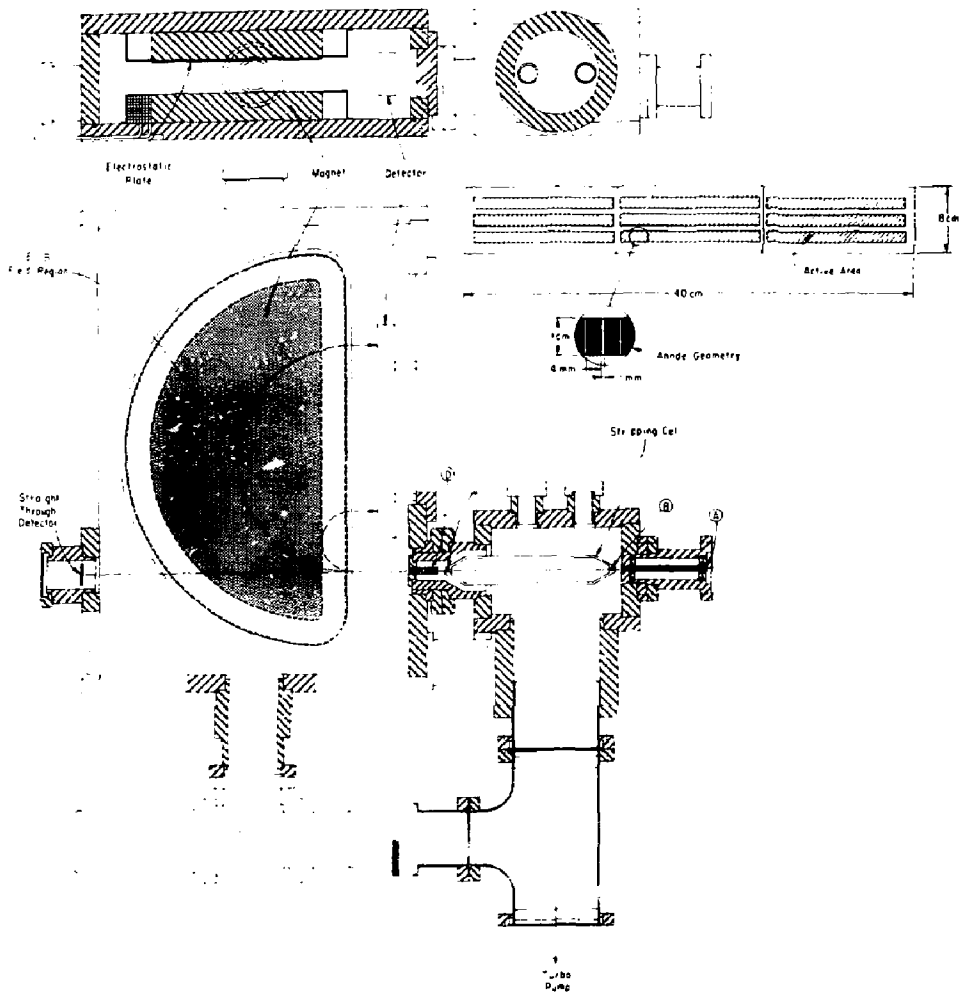

Fig. 1 Cross sectional views in plan and elevation of the prototype E||B charge exchange analyzer for the TFTR diagnostics. (PPPL-803783)

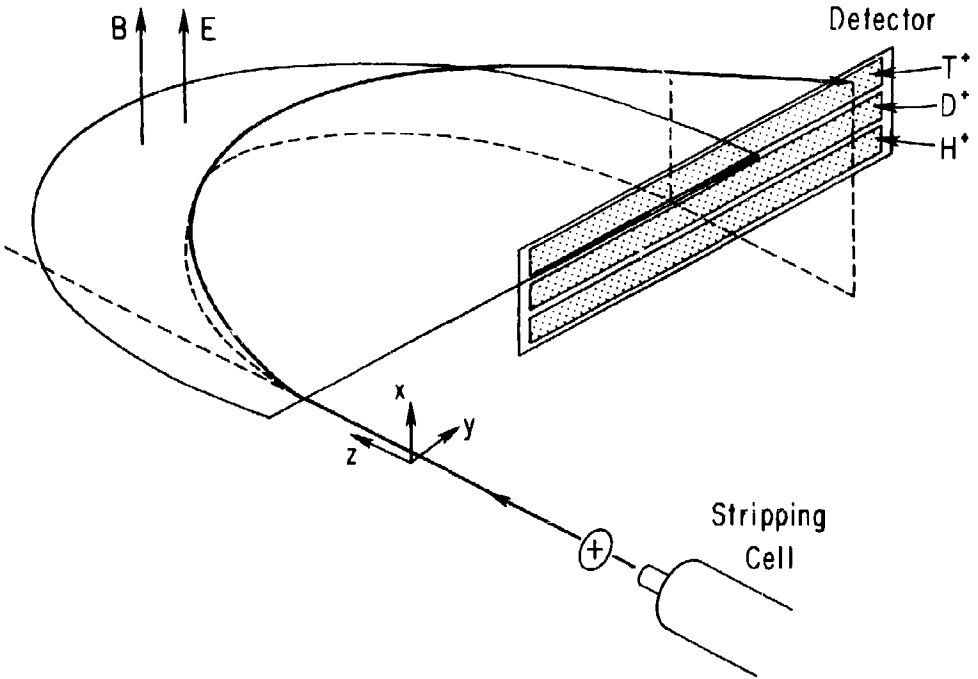

Fig. 2 Sketch illustrating the operating concept of the TFTR E||B charge exchange analyzer. (PPPL-[illegible])

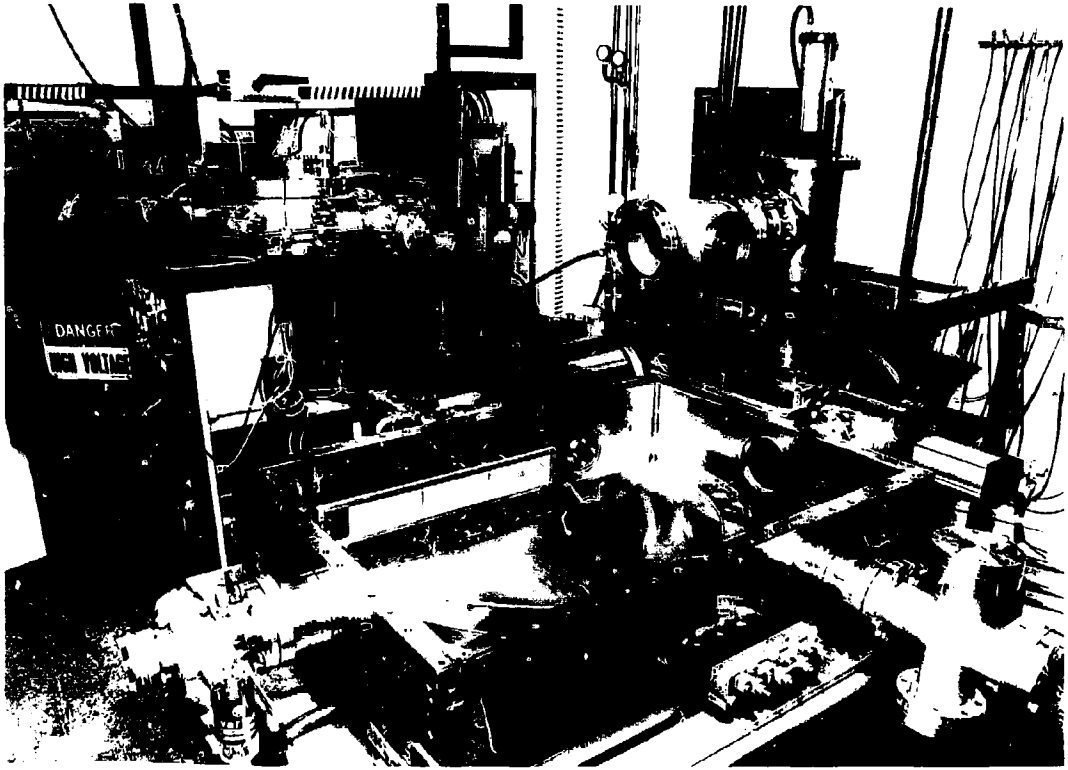

Fig. 3 Photograph of the prototype E||B charge exchange analyzer and 150 keV ion beam calibration source in the Charge Exchange Laboratory (CXLAB). (PPPL-809129)

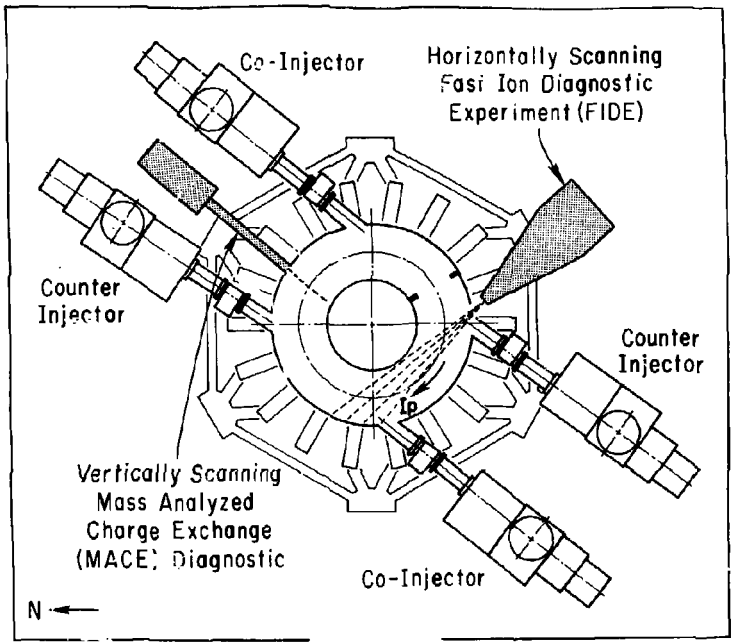

Fig. 4 Plan view of PLT showing the location of the Fast Ion Diagnostic Experiment (FIDE). (PPPL-793767)

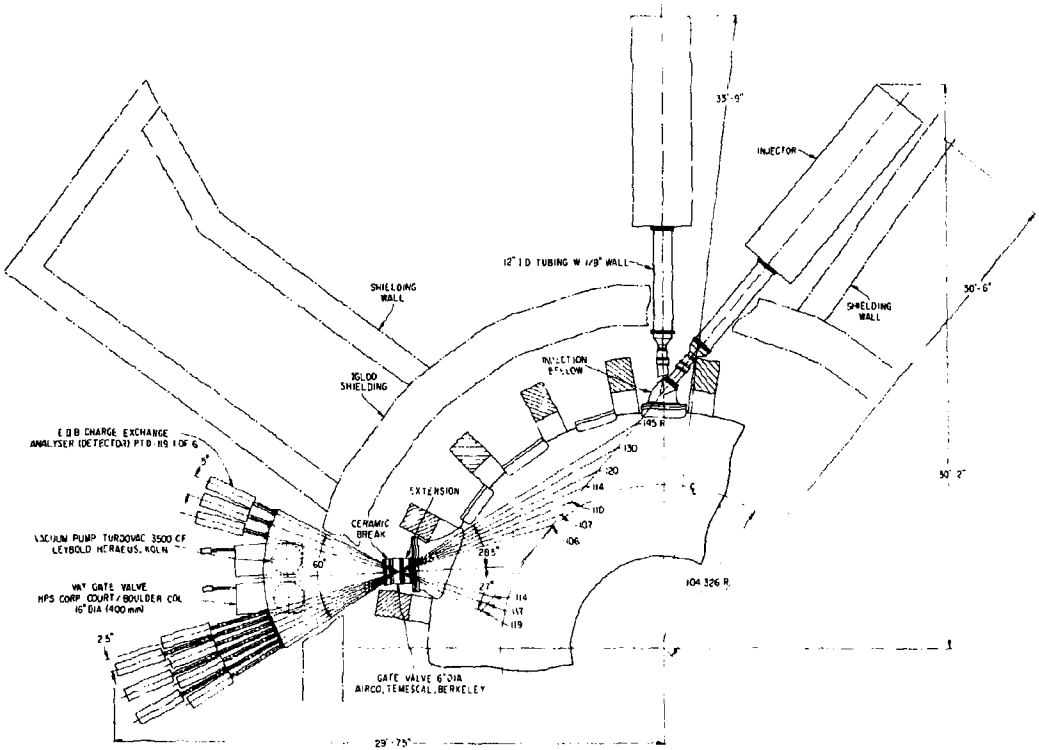

Fig. 5 Plan view of the TFTR torus showing the relative location of the diagnostic neutral beam and the fast ion diagnostic sightline pattern. (PPPL-783808)

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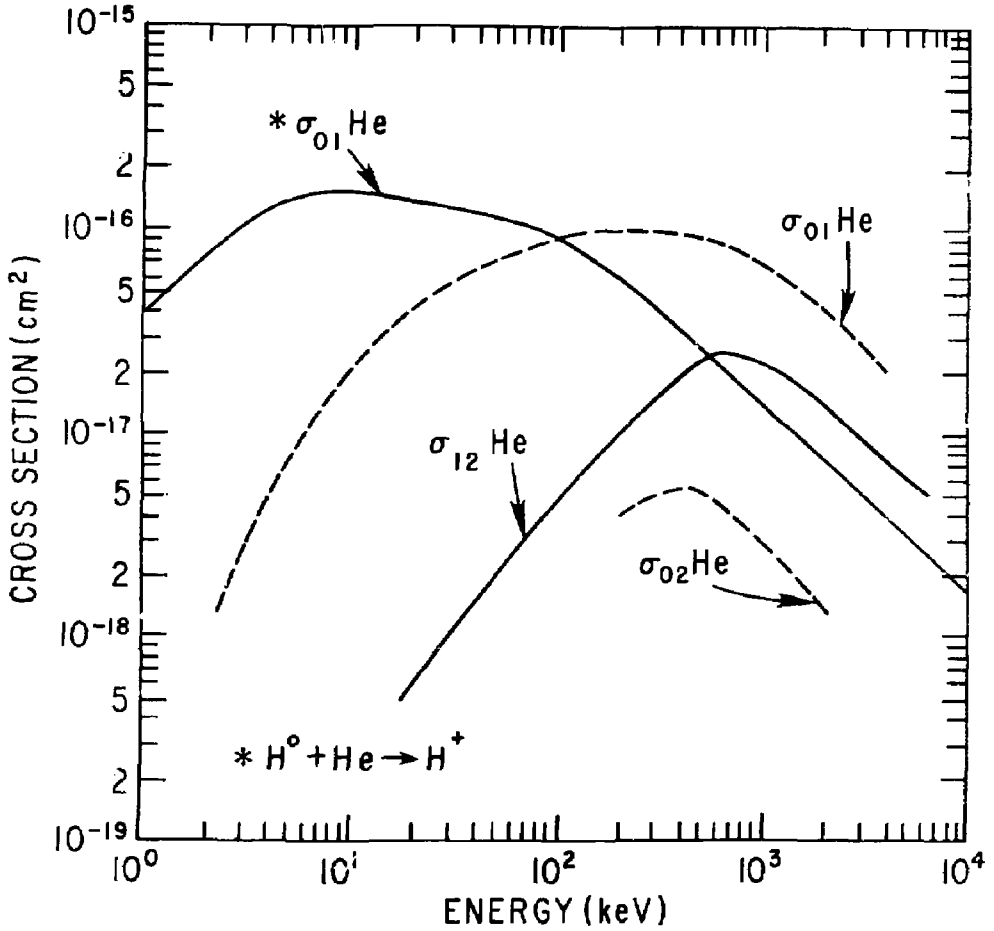

Fig. 6 Cross sections relevant to reionization of He_3^o neutrals in a helium stripping cell. For comparison, the cross section for reionization of H_o in the same gas is also shown.

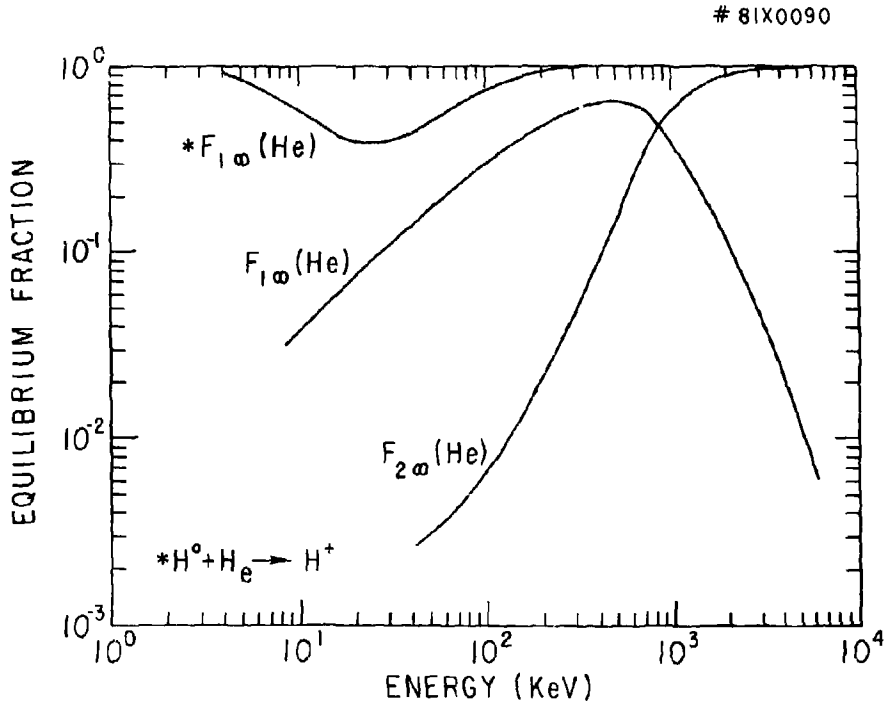

Fig. 7 Equilibrium fractions for singly reionized hydrogen and helium beams in helium gas.

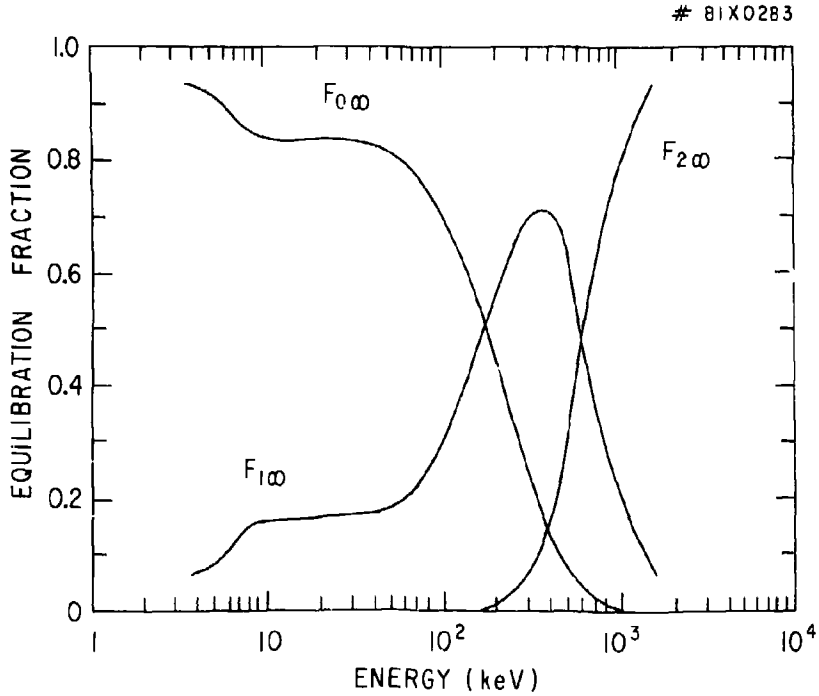

Fig. 8 Equilibrium fractions for helium beams in H_2 gas.