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# ABSOLUTE CALIBRATION OF TFTR HELIUM PROPORTIONAL COUNTERS

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J.D. STRACHAN, C.W. BARNES, M. DIESSO, ET AL.

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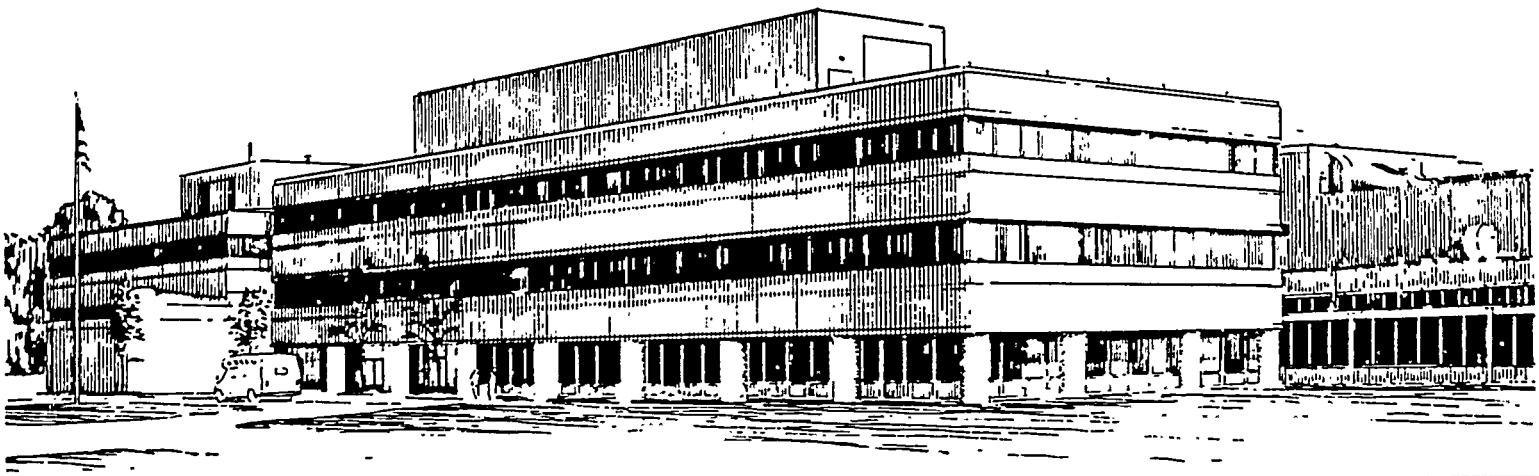

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**Princeton University**
**Plasma Physics Laboratory**

# ABSOLUTE CALIBRATION OF TFTR HELIUM PROPORTIONAL COUNTERS

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**Abstract**

The TFTR helium proportional counters are located in the central five (5) channels of the TFTR multichannel neutron collimator. These detectors were absolutely calibrated using a 14 MeV neutron generator positioned at the horizontal midplane of the TFTR vacuum vessel. The neutron generator position was scanned in centimeter steps to determine the collimator aperture width to 14 MeV neutrons and the absolute sensitivity of each channel. Neutron profiles were measured for TFTR plasmas with time resolution between 5 msec and 50 msec depending upon count rates. The He detectors were used to measure the burnup of 1 MeV tritons in deuterium plasmas, the transport of tritium in trace tritium experiments, and the residual tritium levels in plasmas following 50:50 DT experiments.

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## 1. Introduction

TFTR has performed several experiments where the DT neutron emission is less than or about equal to the DD neutron emission. These experiments have included: the determination of optimal conditions for D-T fusion using trace amounts of tritium; the study of trace tritium transport; the study of the burnup of the 1 MeV triton from the d(d,p)t fusion reaction in deuterium plasmas; and the study of tritium retention following full tritium plasmas. An important measurement for each of these situations is the separate detection of D-D (2.5 MeV) and D-T (14.1 MeV) neutrons. One system which detects the D-T neutron count rate in a mixed neutron field is a set of $^4$He proportional detectors [1,2]. These detectors have been installed along five sight-lines located in the TFTR multichannel neutron collimator [3] that view the plasma from below.

This paper reports the calibration of the TFTR helium proportional counters and also describes modifications to the detector usage which have resulted in better 14 MeV neutron signals compared to earlier work [2]. The component of the signal originating from scattering off the vessel was estimated by observing the count rates from small plasmas shifted out of the detector view. The analysis of the neutron profiles has been accomplished by fitting the line-integrated data to a Gaussian in order to derive the major and minor radii of the DT neutron emission and the intensity of the neutron emission.

## 2. Detector System

The detector system consists of helium proportional counters located in the five central channels of the TFTR multichannel neutron collimator [2,3] (Fig. 1). The detectors are located approximately 8 meters below the midplane of TFTR and are arranged vertically along sight-lines at major radii of 2.23, 2.47, 2.68, 2.99, and 3.15 m. For most TFTR plasmas, the tokamak major radius is in the range from

2.45 to 2.62 m, and the observed full width (half maximum) of the DT neutron emission ranges from 0.3 to 0.6 m. Thus, the five channels of the collimator with the $^4$He detectors are typically the only ones which receive detectable DT neutron fluences. It can happen that the neutron profile is centered between the channels and is narrower than the inter channel spacing, in which case, the $^4$He detectors do not yield as useful information about the plasma. In analyzed cases to date, about 1% of the profiles were in this category.

Each detector [4] has a circular detection head 5 cm in diameter and is oriented to point towards the plasma [2]. The detectors are filled with 20 atm of helium and are operated at 2.8 kV. They produce large energy helium recoils from the 14 MeV neutrons (Fig. 2) while the 2.5 MeV neutrons from D-D fusion reactions and the reduced energy neutrons from scattering produce smaller energy recoils. Counts due to gammas or hard X-rays are not significant for these detectors. The signal from each detector is analyzed electronically with a pulse height analyzer (PHA) and three single channel analyzers (SCAs). The PHA and SCA thresholds allow for the discrimination of incident neutrons according to their energy. The SCAs allow for time resolved detection of neutrons incident within pre-set energy windows (Fig. 2) and effectively discriminate against DD neutrons.

In addition to the calibrations described in the following sections, the system has undergone several improvements since its initial operation [1,2]. The first is the addition of the fifth detector to the original set of four, effectively expanding the radial view area of the tokamak plasma, and providing better characterization of the DT neutron profiles.

Secondly, the frequency response of the detectors has been improved by the replacement of the 2 μs amplifier shaping constant by a 0.5 μs shaping constant. The detectors had previously run into pulse-pileup in the most central channels at

total neutron emission rates of ~ 3.5 $\times 10^{16}$ neutrons/second. Now, similar problems do not occur in mixed neutron emissions until about $5 \times 10^{16}$ $s^{-1}$.

The third improvement in the system was the resetting of the energy windows viewed by the SCAs. The scaler windows are now set up in three overlapping regions with a common upper level-discriminator setting (about 20 MeV), and three distinct lower-level-discriminator settings, all above 2.5 MeV at about 5 MeV, 7.5 MeV, and 10 MeV. In this manner, the SCA discriminates well against 2.5 MeV neutrons, and the ratios of the three SCA channels indicate when pulse pile up occurs, since the count rates increase first in the lower energy settings due to pileup by 2.5 MeV neutron counts. Excessive count rates from D-T neutrons seem to reduce the gain of the pulse amplification causing a reduction in the highest energy signals. There have not been enough TFTR plasmas with the appropriate neutron emission levels for the details of the detector saturation to be studied.

## 3. In-Vessel Calibration

Another improvement in the $^4$He detector system was the calibration of each detector's response to 14 MeV neutrons produced at the TFTR midplane. This is necessary since: (1) the collimator channels contain construction flaws (primarily curvature), (2) scattering from the channel walls occurs, and (3) the neutrons arriving at the $^4$He detectors had to pass through a ZnS detector [5] which is located about 1.7 m above (Fig. 1). The attenuation of the DT neutrons was thus determined by measuring each detector's response to a known-strength DT neutron source that was scanned across the collimator aperture. In February 1993, an absolute calibration was performed using a 14 MeV neutron generator placed inside the TFTR vessel [6] (Fig. 3). The neutron generator accelerates 100 kV deuterons onto a tritiated tungsten target forming a pulsed D-T neutron source

(turned on for about 10 msec at 10 pulses/sec) with an average neutron emission rate of $4 \times 10^7$ $s^{-1}$ [7]. The average count rate for the helium detectors was less than 2 $s^{-1}$ so that the calibration did not suffer from pulse pile-up. The neutron emission from the DT generator was characterized with a ZnS detector [6], a NE213 detector, and activation foils when the generator was operated in an open room. The emission in the direction of the helium detectors was determined by activation of $^{27}Al(n,\alpha)$ foils having a neutron threshold of about 6 MeV. The activation determined the 14 MeV neutron flux and normalized the count rate of a $^{238}U$ monitor detector attached to the generator (Fig. 3). The absolute fluence of DT neutrons directed at the helium detectors was determined to about 6% accuracy for each calibration exposure [6].

The generator was placed in the midplane of the machine on a track that allowed it to be located accurately in various radial and toroidal positions (Fig. 3). The neutron generator was moved across the view area of each collimator channel, and the number of counts was recorded when the generator was operated at each 1 cm increment. Each calibration exposure lasted for 240 seconds, and the yield from the generator was determined from the counts in the normalized monitor detector. Scans in the radial direction were performed for all five collimator channels (Fig. 4), and a scan along the toroidal direction was performed for the most central channel.

The result of each irradiation was the detector point efficiency at that position within the collimator view (Fig. 4). The shape of the scan would ideally be a rectangle; however, curvature and misalignment of the collimator channels causes some deviation from the rectangular shape [5]. In general, the shape of the scans was similar for the $^4He$ detectors as for the ZnS detector irradiated by DT neutrons in the same scan and also for the ZnS detectors irradiated by Cf neutrons.

It is also the same in 1993 as it was in 1990 [3]. Apparently then, the transmission of the collimator aperture is stable and (relatively) neutron energy independent.

The efficiency of each detector was obtained by finding the efficiency at peak sensitivity (e.g., from -1 to 2 cm in Fig. 4) and applying a transmission correction using the model for the collimator deviations based upon curve fitting to the ZnS calibration data [8]. In this manner, an efficiency is obtained for the nominal 7 cm diameter collimator aperture (Table 1). The peak efficiencies of each detector are similar since the amplifier gains had been adjusted so that each detector gave a similar pulse height spectrum when irradiated by Cf neutrons. The sources of uncertainty in the detector calibration are outlined in Table 2, and the total accuracy of the efficiency for each channel is about ± 10% which was obtained by adding the individual uncertainties in quadrature.

There are two sets of ZnS detectors located in the flight path of the neutrons to the helium detectors (about 1.7 m above the helium detectors). Tests were made of the attenuation of the Cf and 14 MeV neutrons by removing the ZnS detectors on some irradiations. It was found that the total count rate was reduced, when the ZnS detectors were present, by a factor of 5.2 for Cf neutrons and by 2.8 for DT neutrons. The DT neutrons were attenuated by a factor of 2.05 for counts above 2.5 MeV, by 1.86 above 5 MeV, and by 1.53 above 10 MeV. Evidently, the ZnS detectors have a significant effect upon the efficiency of the helium detector signals. This further indicates the necessity of performing the absolute calibration with the DT neutrons. The larger effect on the lower energy helium recoil counts probably indicates that some degradation in neutron energy occurred in the collimator system. Further evidence for this is found in the He recoil spectra themselves.

The energy spectra obtained with the Cf source, 2.5 MeV neutron source, and 14 MeV neutron source are sufficiently different that the He detectors count 14

MeV neutrons and not 2.5 MeV neutrons (Fig. 2). The detector response to 14 MeV neutrons generated by the neutron generator is nearly identical (Fig. 5) to that when the neutrons are generated by the plasma, indicating that for recoils created above an equivalent neutron energy of 5 MeV, the detector is responding as if to a pure 14 MeV neutron source. Furthermore, the spectra indicate that all the detectors have been balanced fairly well since each response to the 14 MeV neutron generator is similar (Table 1).

The TFTR detector response has some significant differences from that determined experimentally by Birch [9] for a helium recoil detector. The main differences between the Birch detector response and the TFTR detector response are the existence of a few counts above 14 MeV in the TFTR spectra and of a factor-of-two more counts below about 12 MeV. Possible reasons for these differences include:

(1) The detectors have different designs. The detector characterized in Ref. 9 had a fill pressure of 6 atm of $^4$He and 6 atm of Argon while the TFTR detectors have 20 atm of He. The detector of Ref. 9 had the same diameter as the TFTR detector but was shorter (30 cm vs. 70 cm). The effect of these differences on the neutron spectra have not been evaluated.

(2) Pulse pile-up effects for the counts above 14 MeV could occur since the count rate is much higher in the TFTR plasma case than in the calibration. The magnitude of this tail indicates that pile-up has an insignificant effect on the helium recoil count rate above 5 MeV.

(3) The TFTR spectra have more counts below 12 MeV which may be an indication of the existence of neutrons of degraded energy due to scattering from the TFTR vessel, the collimator aperture, and the ZnS detectors above the He detectors. Since the spectral shape is identical

for 14 MeV neutron generator and TFTR plasma operation, this means that the generator calibration is effective at determining the detector response to those scattering processes.

(4) The counts above 15 MeV may be due to high energy neutrons created in beam-beam reactions in the plasma which do not occur in the generator.

## 4. Backscattered Correction

The helium proportional counters measure the flux of 14 MeV neutrons which travel down each collimator channel. Previously [3], it was found that for the ZnS detectors, the channel cross talk is negligible but that $\approx$ 5-10% of the measured neutron signals could arise from neutrons that enter the collimator after scattering from the collimator entrance aperture or from the TFTR vacuum vessel and other machine components within the view of each channel [10]. This scattered component is more important for the channels which view the outer portions of the plasma since the directly-viewed plasma neutron emission can be greatly reduced off-axis while the scattered component will tend to be about constant.

The scattering correction was estimated by the method described in Ref. 10. Several small minor radius TFTR plasmas were operated in a manner which resulted in each channel observing only scattered neutrons. An in-shifted R = 2.15 m, 1.0 MA TFTR plasma meant that channels 6,7, and 8 (Figs. 6 and 7) did not view the plasma while an R = 3.00 m, 0.7 MA TFTR plasma meant that channel 4 did not view the plasma and channel 5 viewed only the edge of the plasma (and presumably not the neutron emitting region of that plasma). These plasmas were heated by 2.2 MW of deuterium neutral beams having a nominally 2% tritium concentration yielding a D-T neutron emission in the range of $10^{15}$ D-T

neutrons/sec for 0.5 sec. Three each of these plasmas were run to accumulate counting statistics. The D-T neutron emission was measured by the TFTR fission detectors and activation system whose sensitivity to plasma position have been determined.

As shown in Fig. 7, the scattering correction is small for the helium proportional counters ($\approx$ 1% of the unscattered flux for a channel viewing the plasma center), making the correction negligibly important for unfolding the data. The helium proportional counters are more effective than the ZnS detectors at discriminating against scattered neutrons, since the He detectors have energy resolution while the ZnS detectors do not.

## 5. Applications

For TFTR data, the five point profiles of the line-integral neutron emission have been fit to a Gaussian. The major radius, minor radius, and total emission intensity of the Gaussian are determined [1,2]. Typically, it has been important to determine gain shifts between the February 1993 calibration and the November 1993 to February 1994 plasma operation by comparing the pulse height spectrum taken during plasma operation with the pulse height spectrum taken during the calibration. Several validity checks on the profile data are useful including that the major radius is similar to the Shafranov shifted plasma center, and that the magnitude of the 14 MeV neutron yield is comparable to the 14 MeV neutron yield measured by the other TFTR detectors such as the activation system [10].

**Acknowledgment**

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**TABLE 1. Detector Efficiencies in Counts above 5 MeV per 14 MeV Neutron**

| Channel | R (m) | Peak Efficiency ($10^{-9}$ cts/DTn) | reff (cm) | Average Efficiency ($10^{-9}$ cts/DTn) |
|---|---|---|---|---|
| 4 | 2.26 | 2.92 | 6.79 | 2.75 |
| 5 | 2.47 | 2.92 | 6.46 | 2.49 |
| 6 | 2.68 | 2.61 | 6.63 | 2.34 |
| 7 | 2.99 | 2.71 | 5.71 | 1.80 |
| 8 | 3.15 | 3.02 | 6.99 | 3.01 |

**TABLE 2. Typical Sources of Error**

| | |
|---|---|
| Uncertainty in Calibration of Individual Channels | |
| (a) Source Uncertainty | ± 6% |
| (b) Statistics of Monitor Detector | ± 0.5% |
| (c) Statistics of $^4$He Detector | ± 6% → ± 7% |
| (d) Aperture Deformation Modeling | ± 5% → ± 10% |
| Total | ± 10% → ± 13% |
| Use During Plasma Operation | |
| (a) Stability of Electronics (gain changes) | ± 4% → ± 10% |
| (b) Statistics of $^4$He Detector | ± 5% (typical) |
| (c) Gaussian Profile Assumption | ± 5% |
| Total Accuracy for Determining the Neutron Intensity | ± 12% → ± 15% (typical) |

## Figure Captions

Fig. 1. Layout of the TFTR multichannel collimator indicating the poloidal cross-section of the TFTR plasma, the helium detectors, and the lines-of-sight of the collimator channels into the plasma.

Fig. 2. Pulse height spectra from the helium proportional counter in the sixth collimator channel when irradiated by the 14 MeV neutrons (data points with error bars), and by the 2.5 MeV neutrons (solid line). The SCA lower level discriminator settings are at channels 100, 150, and 200 indicating excellent discrimination between 14 MeV and 2.5 MeV neutrons.

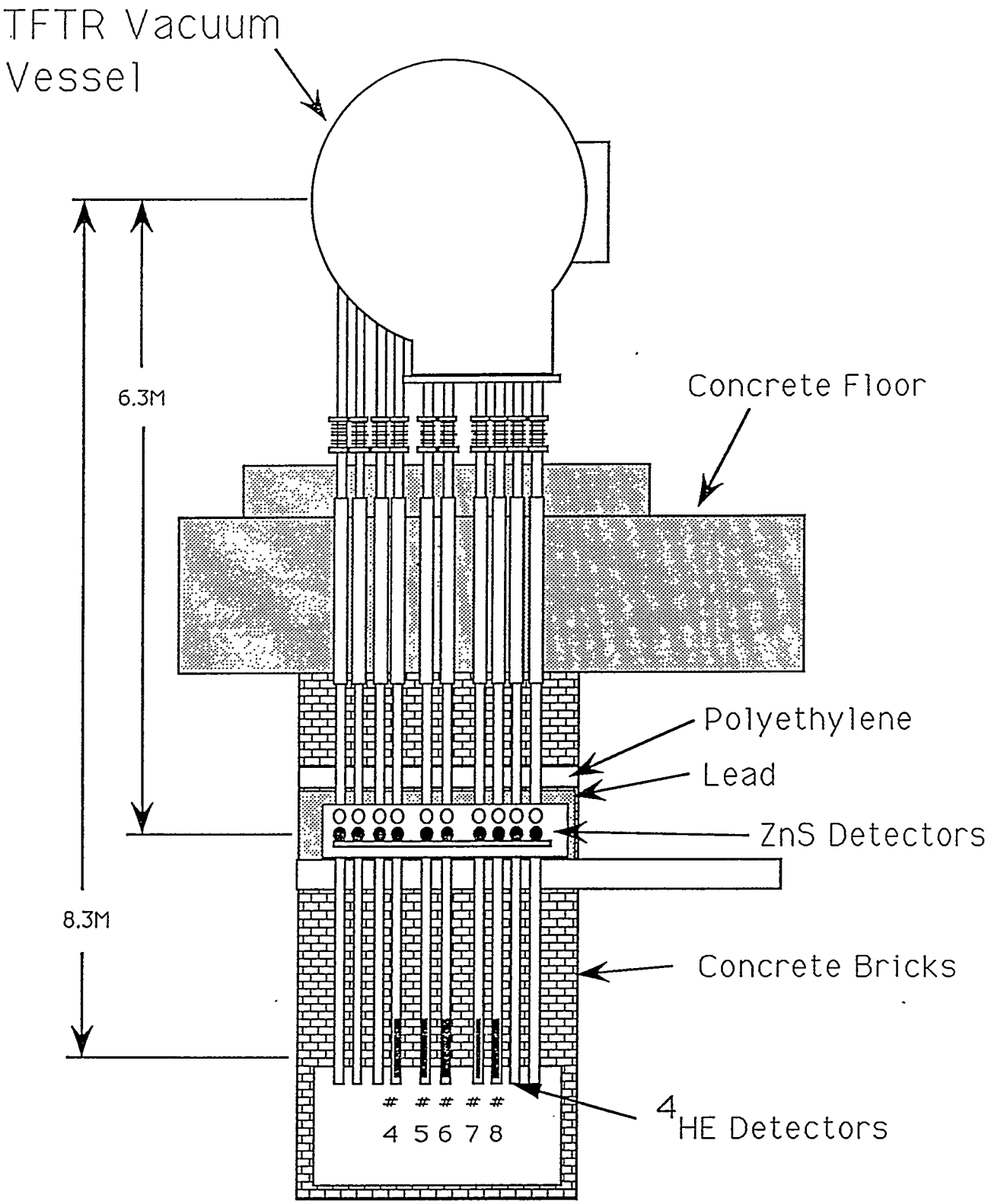
Fig. 3. The 14 MeV neutron generator located inside the TFTR vessel during the absolute calibration of the helium proportional counters. The accelerator target is located at the near end and the $^{238}U$ monitor detector is mounted on this side of the generator. The monitor detector is wrapped in braid to avoid electronic noise pick up from the generator.

Fig. 4. The efficiency of the $^{4}He$ detector to the neutrons from the DT generator when the generator was scanned across the aperture of the fifth collimator channel. The error bars on the $^{4}He$ counts are due to counting statistics and due to the positioning accuracy of the DT generator.

Fig. 5. He detector counts for collimator channel #6 (normalized at PHA channel 250) versus pulse height when exposed to 14 MeV neutrons from a TFTR plasma shot (solid points), when exposed to 14 MeV neutrons from the DT generator (situated in the TFTR vessel), (open squares), and as predicted for 14 MeV monoenergetic neutrons from Ref. 11 (x-points).

Fig. 6. Plasma location of the in-shifted and out-shifted TFTR trace tritium plasmas used to estimate the backscattered neutron contribution in each channel.

Fig. 7. Detector counts normalized to total D-T neutron emission in the backscatter calibration. The open squares are for the in-shifted position and the closed squares are for the out-shifted position.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Concrete Bricks
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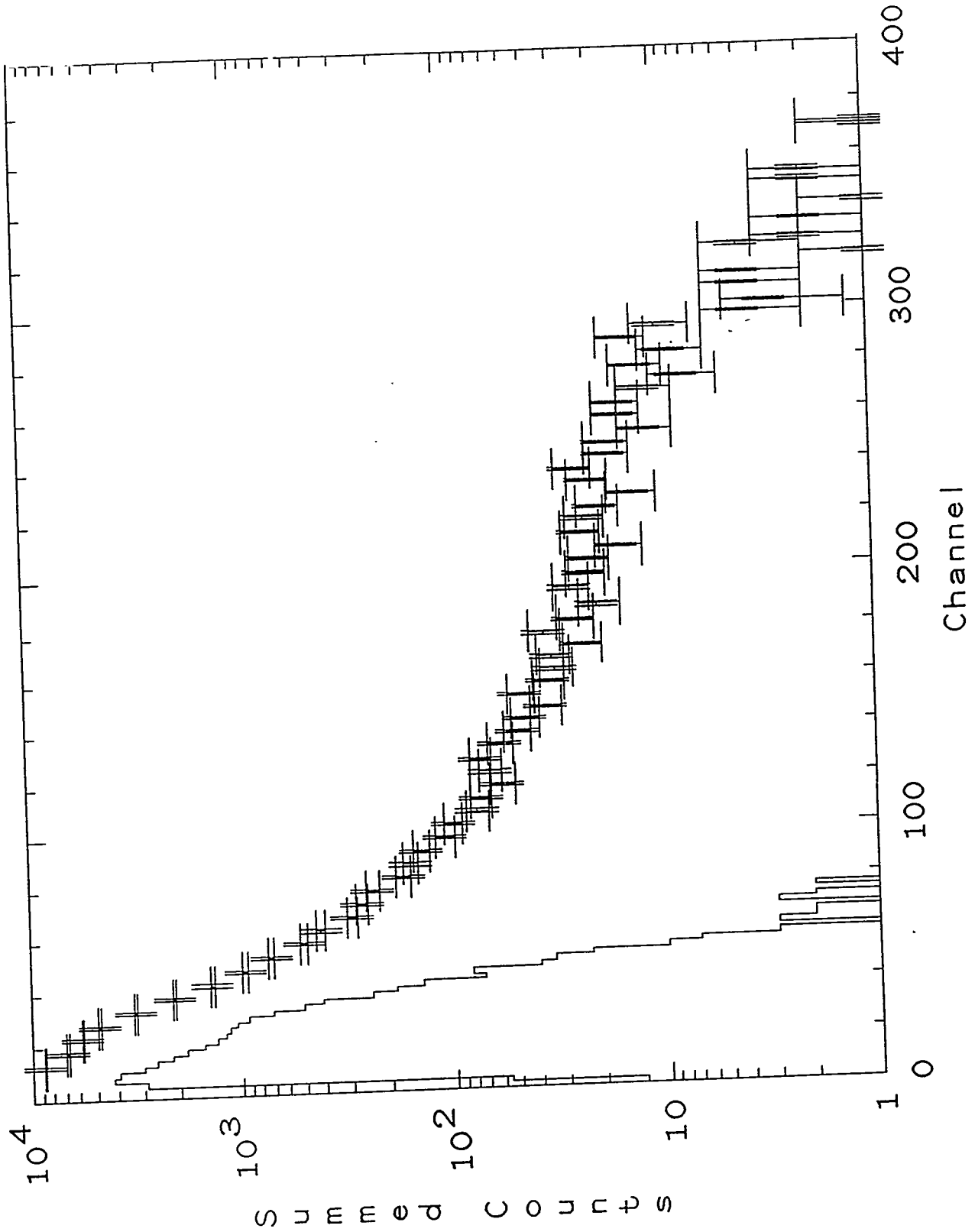
Fig. 1

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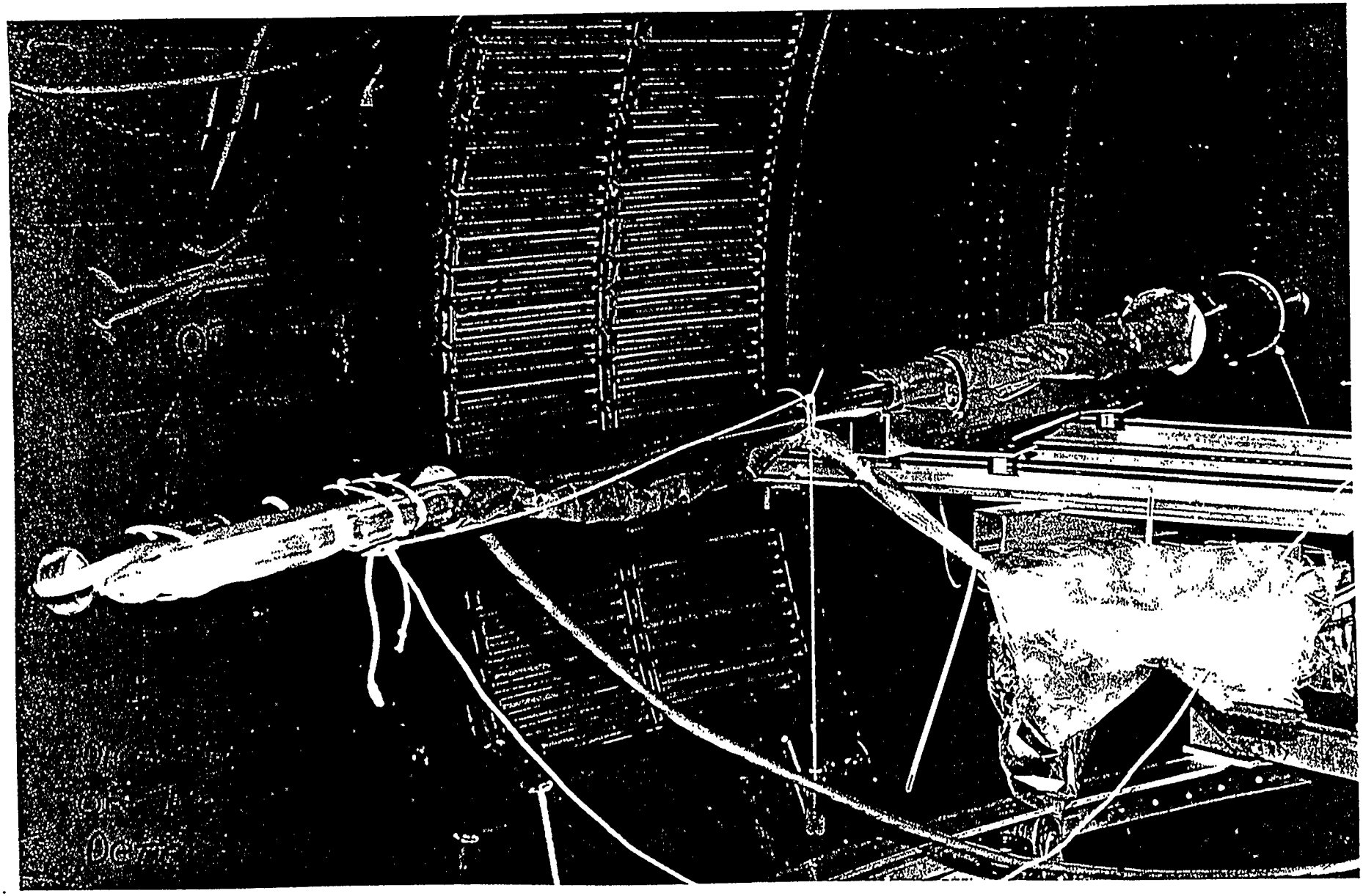
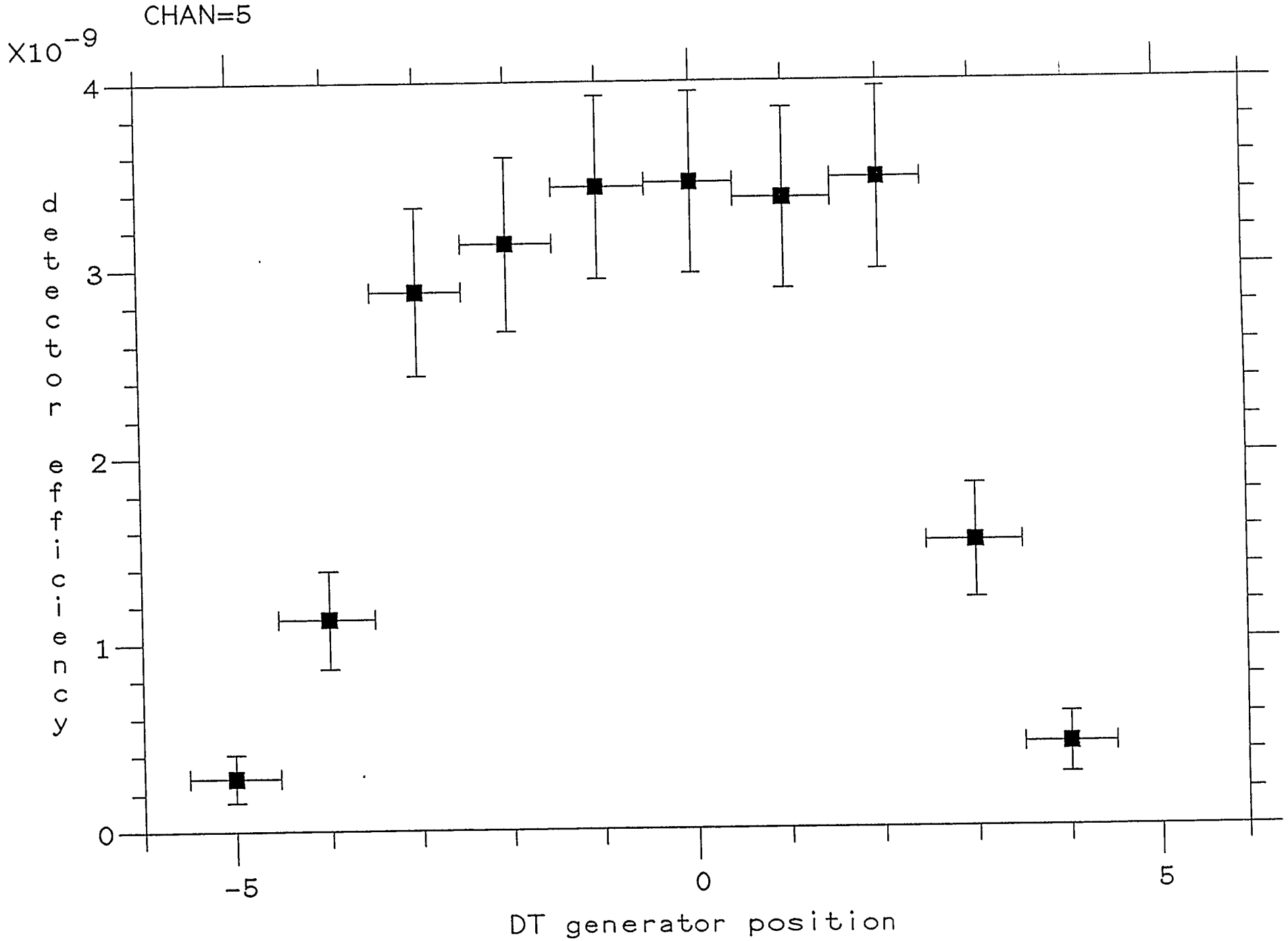


Fig. 3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DT generator position

Fig. 4

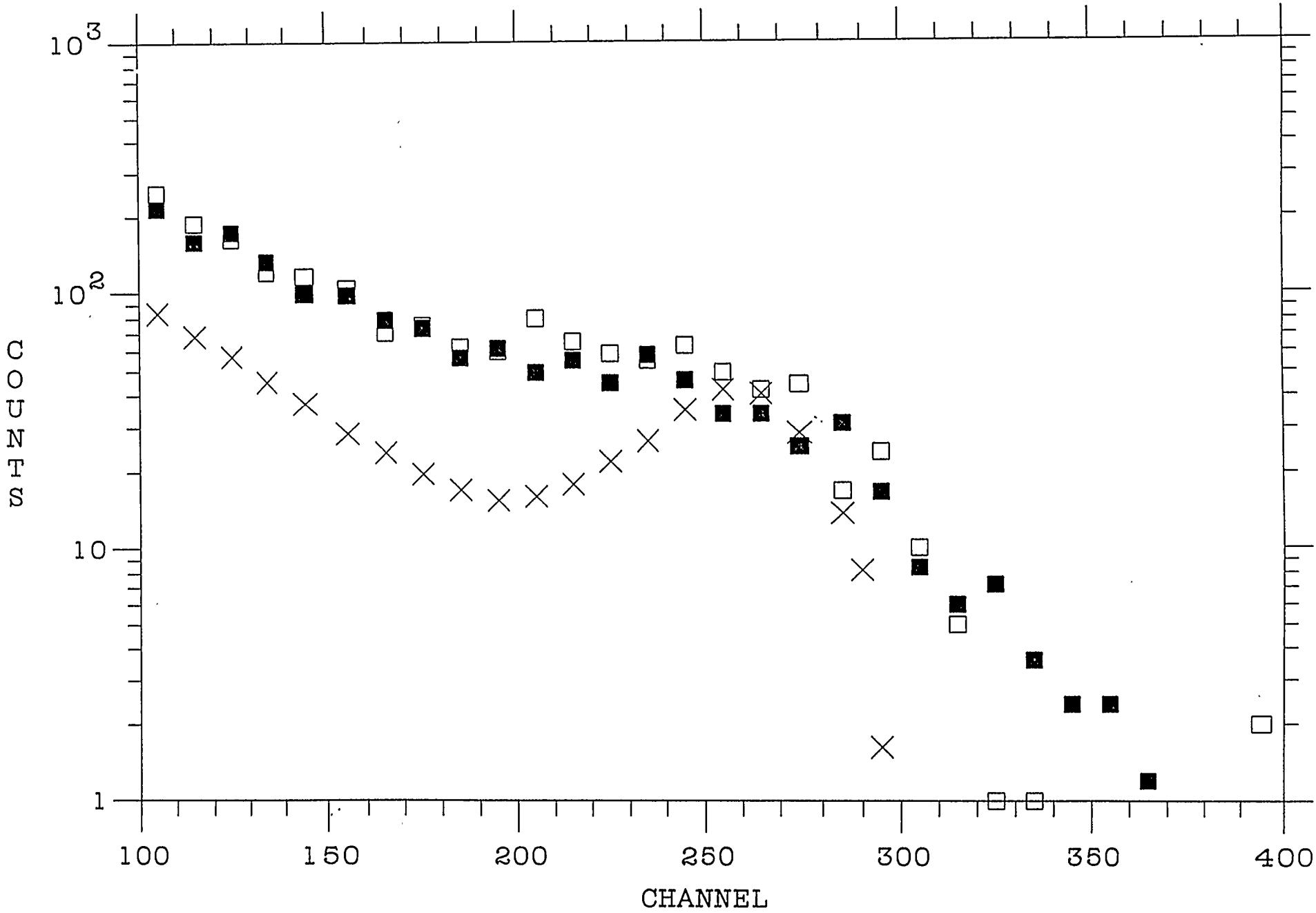


Fig. 5

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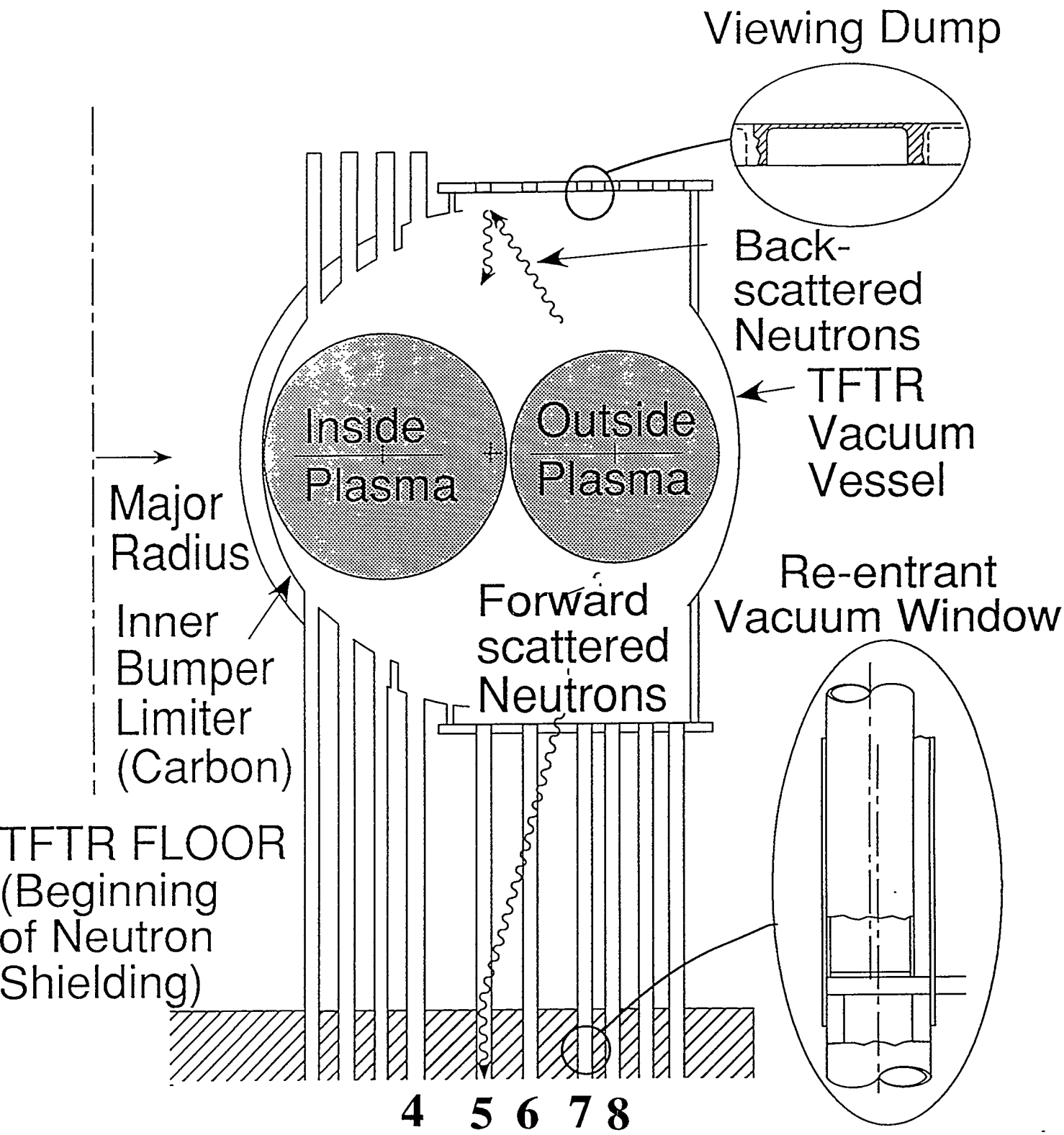


Fig. 6'

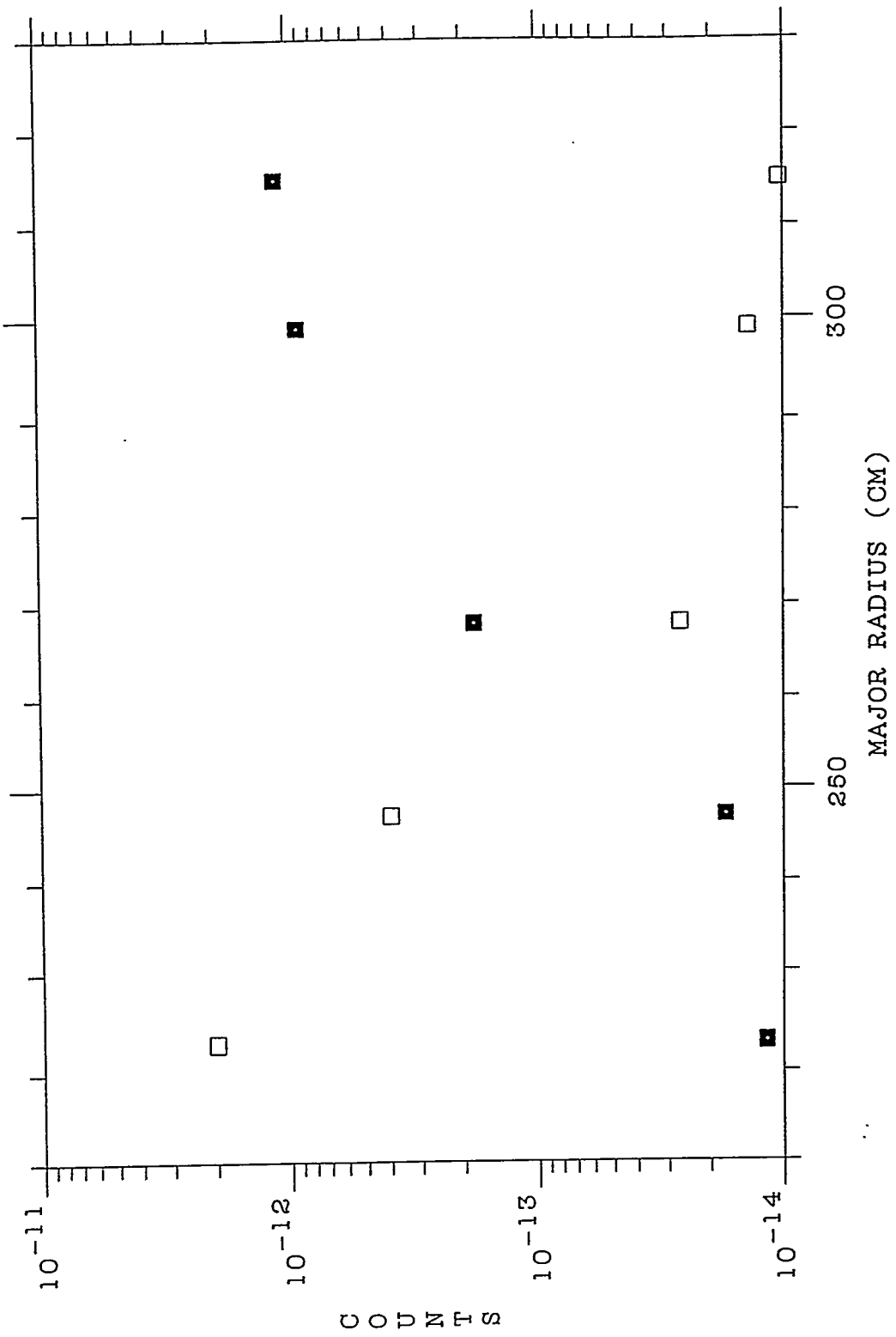


Fig. 7

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