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MULTI-CHANNEL NEUTRAL ANALYZER-SYSTEM

W. E. Nexsen, Jr., W. C. Turner, W. F. Cummins

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W. E. Nexsen, Jr., W. C. Turner, W. F. Cummins

Introduction

An important diagnostic technique for the investigation of hot plasmas is the analysis of the energetic neutral particles escaping the plasma.¹⁻⁹ Usually the energetic neutrals are the result of charge exchange reactions between background gas and the plasma ions. In general, because of the short penetration depths of the background gas into the plasma, the measured distributions are mainly characteristic of the ion distribution near the plasma surface. In some of the present generation of plasma experiments however the neutrals are due primarily to charge-exchange reactions between plasma ions and the energetic neutral beams used to feed and heat the plasma. In the case of the LLL mirror machine 2XIIB, for instance, the signal with the beams on is of the order of one hundred times as strong as that with the beams off. Such a strong source provides the opportunity to study the behavior of the plasma energy distribution in much more detail than has been possible heretofore.

The early neutral analyzers and some of the more recent ones had only a single channel; consequently the reduced data are the result of a number of machine cycles (or at least are taken at different times in case of a swept analyzer). In this process shot-to-shot variation is averaged out and information has been lost. To avoid this loss of information there has been a

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trend toward multi-channel analyzers. The use of these multi-channel analyzers accentuates the problem of calibration; however, since the channels may not have the same gain, energy acceptance, or angular acceptance. We describe here an approach, borrowed from optical spectroscopy, which we have adopted to solve this problem.

The energy distribution of ions trapped in a mirror machine is necessarily non-Maxwellian, consequently the distribution should be measured over its entire energy range. To obtain the desired detail, the neutral analyzer must have a large number of channels. We have developed for the 2XIIB experiment a fifteen-channel analyzer system which satisfies these requirements:

- Simultaneous data recording at fifteen points on the energy distribution.
- Frequency response DC - 50 kHz.
- Spatial resolution, in order to study variations of flux and energy distributions along different chords through the plasma.
- Mass resolution, since impurities may be of importance and we operate with H^+ and/or D^+ in the guns/beams/gas box.
- A data acquisition and processing system which outputs reduced data within 30 seconds after a shot.
- A simple system for maintaining the absolute calibration of the analyzer.

II. Description

A. Apparatus

The analyzer is sketched in Fig. 1. Energetic neutrals from the plasma pass through a gas stripping cell where 0.1-10% are ionized. These ions then are deflected by the magnet and may be sampled by one of the fifteen electrostatic analyzers arranged over the interval from 18° to 108° of particle deflection. The momentum analysis due to the magnet when combined with the energy analysis of the electrostatic analyzer allows one to choose neutrals of a particular mass and measure as a function of time fifteen points on their energy spectrum. The data is recorded by a fifteen channel digital recorder and processed by a minicomputer. At present the system covers the energy range from 500 eV - 50 keV for deuterium and all probable impurities.

The requirement of high counting rate necessitates large apertures in the stripping cell. The limiting apertures are 0.95 cm in diameter and the cell length is approximately 28 cm when end effects are taken into account. The stripping gas is nitrogen at 5×10^{-4} torr pressure. Two stages of differential pumping drop the pressure by a factor of 200 and further isolation between the cell and the main machine is furnished by a low conductance beam tube and titanium gettering in the machine side arm.

The magnet poles have an effective diameter of almost 30 cm. Maximum field in the 2.5 cm gap is near 1 Tesla and the flux is returned coaxially. The magnet and electrostatic analyzer region are pumped by a turbo pump and liquid nitrogen cold finger.

Figure 2 shows one of the 90° deflection, parallel plate, electrostatic analyzers. These are designed with a rather large $\Delta E/E$ of about 7% to increase the sensitivity and angular acceptance. Overall thickness of the

analyzer was kept to 5 cm to allow for close packing of the fifteen analyzers. This required the inclusion of a voltage divider network and associated guard rings to create a uniform electric field.

The detector is patterned after one first used by Schutze & Bernhard.¹⁰ In this detector incident ions are accelerated by the HV potential (nominally -18 kV), pass through a high transmission double grid and strike the opposite interior wall of the emitter where they produce secondary electrons. The electric field penetrating the open end of the emitter accelerates these electrons into a plastic fluor. About 5 keV of the electron energy is lost penetrating the 2000 $\text{\AA}$ thick aluminum plating on the fluor; the remainder of the energy produces a light pulse which is detected by a photo multiplier. Single ions can be detected but the system is normally run in a current mode by integrating the signal ($RC \approx 5 \mu\text{s}$).

Mounted on the multichannel analyzer system described above is a second independent single channel electrostatic analyzer with a separate stripping cell. The axes of both this auxiliary analyzer and the multichannel analyzer lie in the centerplane of the 2XIIB experiment and are displaced azimuthally with respect to one another by an angle of $\sim 5^\circ$ in order that both are aimed at the same plasma volume. The auxiliary analyzer is calibrated on a separate test stand, (this procedure is described in Section III) and the multi-channel analyzer is calibrated by comparing the signal from the plasma on each channel in turn with the signal from the calibrated analyzer tuned to the channel energy.

A feature of the total system is the ability to make radial scans of the plasma. The majority of the signal is due to charge exchange of plasma

ions with the 2XIIB neutral beams which are injected approximately perpendicular to the axis of the analyzers. The field of view of the analyzers is small compared with the plasma radius and the analyzer signal originates in the volume defined by the intersection of the field of view with the plasma-neutral beam system. The entire neutral analyzer system is mounted on curved rails enabling one to scan from -12 to +12 cm radially.

B. Data Acquisition System

A system of 16 transient recorders¹¹ is used to digitize and store the analog signals from the multichannel and auxiliary analyzer during an experimental pulse. Each of these recorders can digitize and store 4096 words of 10-bit data at a maximum rate of 200 kHz. The usual digitizing rate is 100 kHz for 2000 words resulting in a multichannel analyzer data base of 30,000 words/shot. These recorders also contain digital-to-analog converters which allow the operator to display the signals on an oscilloscope or plotter. Following a pulse the 2XIIB data system¹² reads the data from the recorder system and stores it along with the rest of the diagnostic data on digital disc storage for processing and as a magnetic tape archive file.

III. Auxiliary Analyzer Calibration

A. Procedure

This single channel instrument is calibrated over the energy range of interest, (500 eV to 40 keV) with an atomic beam. In the course of calibration we obtain the energy resolution, angular acceptance and absolute calibration of the single-channel analyzer. The absolute calibration yields the

source brightness. Specifically, we define the parameter $C(E)$ which is the object of our calibration,

$$C(E) = \frac{1}{A\Delta\Omega} \frac{1}{\Delta E} \frac{I_0 g}{V}$$

where A is the analyzer aperture area, $\Delta\Omega$ is the solid angle viewed by the analyzer, ΔE the energy passband, I_0 the equivalent neutral current entering the analyzer aperture, V is the signal recorded by the detector and g is the relative detector gain. Provided the source fills the analyzer field of view, multiplying the detector signal by $C(E)$ and dividing by the detector gain gives the source brightness in amps/cm²-str-eV.

A schematic of the auxiliary analyzer and atomic beam calibration apparatus is shown in Fig. 3. The analyzer is similar to the other fifteen analyzers of the multichannel apparatus. The design provides first order focusing of the entrance aperture onto the exit aperture in the plane perpendicular to the plates. The energy of the beam passing through the analyzer is related to the plate voltage V_p by

$$E = \frac{x}{2d} V_p$$

where $d = 7.7$ cm is the plate separation and $x = 19.7$ cm is the distance between entrance and exit apertures. The energy luminosity (FWHM) is given by

$$\frac{\Delta E}{E} = \frac{\Delta x}{x}$$

where x is the aperture width. The entrance and exit apertures are circular with diameter $D = 0.95$ cm, giving an effective $\Delta x = \frac{\pi}{4} D = 0.75$ cm. The high-voltage plate has an opening covered by a high-transmission grid through which the undeflected beam can pass. Directly behind the parallel plate analyzer is a gridded analyzer. This analyzer can be operated as a simple

Faraday cup, as a secondary electron emission detector, or as an energy analyzer. The analyzer consists of five high-transmission grids. The entrance grid and third grid are grounded. The second grid (actually a double grid) is the ion repeller and the fourth grid is used to extract or repel secondary electrons emitted in the cup detector. The net transmission of these grids has been measured with a light beam and photomultiplier and calculated from the size of grid wires measured with a microscope and found to be 72% by both methods. The parallel plate analyzer detector is of the type described in the introduction. The gas stripping cell is similar to the one used on the magnetic multichannel analyzer. The apertures of the stripping cell are 0.95 cm in diameter and the effective length is 9.2 cm. The stripping cell is operated with nitrogen at 1.0×10^{-3} torr. The stripping cell is differentially pumped and is feedback regulated at the desired pressure.

An rf ion source was used to supply hydrogen or deuterium ions and neutrals for the calibration. A gap-lens extractor furnishes a diverging beam from the source aperture which simulates the plasma emission of neutrals. A large enough fraction of the extracted ion beam is neutralized by ion source gas escaping through the extraction orifice so that it has not been necessary to include a neutralization cell. The ion source is mounted on a drift tube that pivots about the entrance aperture to the stripping cell. The distance from the pivot point to the ion source extraction aperture is chosen to be equal to the distance between the entrance aperture and the centerline of the 2XIIB experiment when the analyzer is installed on the experiment. Deflection plates near the end of the drift tube are used for selecting only the neutral component of the beam. Before mounting the analyzer at the end of the drift tube a fluorescent plate was used to align the ion source with the axis of the drift tube.

In order to calibrate the single channel analyzer, we must first make a number of subsidiary measurements to determine the neutral current incident on the stripping cell. A schematic diagram and the equations used are given in Table I. The symbols in Table I have the following definitions:

γ_0/γ_+ = secondary electron emission coefficient of the Faraday cup for neutral/charged particles.

f_0/f_+ = secondary emission coefficients of the electron suppressor grid for neutral/charged particles.

ϵ/ϵ' = stripping efficiency of gas cell with/without flow of N_2 .

I^0/I^+ = neutral/charged current incident on stripping cell.

T = transmission of grids (gridded analyzer and parallel plates)
= 0.63

The value of $T = 0.63$ is obtained by extrapolating the five-grid value of 0.72 to seven grids.

In general the secondary electron emission coefficients are not the same for neutral and charge species. To analyze the data we have assumed a constant fixed ratio $s = \frac{f_0}{f_+} = \frac{\gamma_0}{\gamma_+} = 1.1$ over the energy range of interest for D^0 and D^+ incident on a "dirty" surface.¹³ For each measurement in Table I we have indicated the condition of the deflection plates, analyzer, secondary grid suppressor bias and whether or not N_2 is admitted to the stripping cell. In essence these measurements use the positive current I_+ from the ion source to measure the secondary emission coefficient γ_+ of the cup detector. Assuming a constant ratio $s = \frac{\gamma_0}{\gamma_+} = 1.1$ of secondary emission by neutral compared to charged particles, the neutral current I_0 from the ion source is measured.

Then gas is admitted to the stripping cell and the ratio of Faraday cup current to neutral current gives the stripping efficiency. The procedure outlined in Table I does this while allowing for systematic effects of grid secondary emission and stripping by background gas. The currents measured in Table I can easily be solved for the physical quantities of interest. If we neglect second-order quantities in the small parameters ϵ' , f_+ , f_0 we obtain

$$\gamma_+ = \frac{(I_4 - I_2) - (I_3 - I_1)}{(I_3 - I_2) - \frac{I_5}{I_6} (I_4 - I_2)}$$

$$f_+ = \gamma_+ \frac{I_5}{I_6}$$

$$\epsilon' = \frac{(I_1 - I_5)}{I_2 - (1 - \gamma_0) (I_1 - I_5)} \gamma_0$$

$$I_+ = \frac{(I_3 - I_1)}{(1 + f_+)} T$$

$$I_0 = \frac{I_6}{\gamma_0 (1 - \epsilon')} T$$

$$\epsilon = \frac{I_7}{T I_0} - f_0.$$

After a measurement of neutral current is made the parallel plate analyzer voltage is tuned to maximum signal V and the ratio $\frac{I_0 g}{V}$ is obtained. The parameter g is the relative current gain of the photomultiplier, arbitrarily

taken to be unity at a photomultiplier supply voltage of $V_s = 2000$ volts.

To a good approximation, $g = \left(\frac{V_s}{2000} \right)^{9.615}$ for the particular photomultiplier we used (RCA8575), over the range $1200 < V_s < 2500$ volts.

B. Results

In this section we describe the results of the calibration procedure outlined above. To present the final results, calculations using the raw current I_1 to I_7 and the equations in Table I are corrected for two effects: (1) the finite energy spread of the ion source beam; (2) the half-energy component of the beam. The finite energy spread of the beam has the effect of reducing the signal recorded on the scintillator-photomultiplier detector compared to a mono-energetic beam. This correction is negligible where the intrinsic energy width of the beam is small compared to the energy passband of the parallel plate analyzer, or for $E \geq 4$ keV for our data. Since the energy luminosity $\frac{\Delta E}{E}$ of the parallel plate analyzer is constant, independent of E , the intrinsic energy width of the beam can be determined by subtracting in quadrature this constant value from the observed $\frac{\Delta E}{E}$ obtained by sweeping the plate voltage of the analyzer. Recorded peak signal strengths are multiplied by the ratio of the total observed energy width to the intrinsic analyzer width. At the lowest energy ~ 500 eV for which we have calibrated the analyzer this correction can amount to a five-fold increase of the recorded signal in the case of poor source operation. A half-energy component of the beam, obtained by acceleration and dissociation of D_2^+ , results in a current that is detected by the Faraday cup but not by the scintillator-

photomultiplier detector when the analyzer is tuned to the full-energy component. The fractions of half-energy and molecular components of the beam depend sensitively on the operating conditions of the rf ion source. We have tuned the rf ion source to optimize the full energy component and for our data the half-energy component was always less than 18% of the full-energy component. The presence of a half-energy component raises the question of a possible full-energy component of D_2^0 and D_2^+ in our beams which we cannot isolate from the atomic component. Magnetic analysis of the calibration beam in the past have shown that under good operating conditions, the stripped beam contains about 15% full-energy molecular ions. Correction for this component requires knowing the ratio of the secondary emission coefficients of the atomic ion to the molecular ion of the same energy. We assume that the coefficients are the same and believe that in making this assumption we have affected the overall results by at most 15%.

In Fig. 4 we have shown the angular acceptance of the stripping cell-parallel plate analyzer-scintillation detector combination in the plane of the analyzer ($\delta\theta_{||}$) and in the orthogonal direction ($\delta\theta_{\perp}$). The data shown represent the full width half maximum of the detector signal as the beam tube is pivoted about the stripping cell entrance aperture. Although there is some scatter in the data, above ~ 1.5 keV the angular acceptance is independent of energy and consistent with the geometrical constraints of apertures. In the plane of the analyzer, where the analyzer field is focusing, the limiting apertures are the entrance to the stripping cell and the entrance through the grounded plate of the analyzer. In the orthogonal direction, the analyzer

is not focusing and the limiting apertures are the stripping cell entrance and the exit through the grounded analyzer plate. Below 1.5 keV the angular acceptance rises rapidly due to increased angular scattering by atomic collisions in the stripping cell. For $E > 1.5$ keV the angular acceptance of the analyzer is

$$\Delta\Omega = \frac{\pi}{4} (\delta\theta_{\parallel}) (\delta\theta_{\perp}) = 1.9 \times 10^{-4} \text{ steradians.}$$

The energy full-width half-maximum of the detector signal is plotted versus energy in Fig. 5. Above 4 keV, $\frac{\Delta E}{E} = 0.035$, independent of energy, and in reasonable agreement with the theoretical result $\frac{\Delta E}{E} = \frac{\Delta x}{x} = 0.038$. Below 4 keV the finite energy spread of the beam causes the observed $\frac{\Delta E}{E}$ to increase slowly as the beam energy decreases.

The stripping efficiency ϵ is plotted versus beam energy in Fig. 6. Below 2 keV the stripping efficiency falls rapidly as beam energy decreases and this, plus decreasing ion-source currents, prevented us from extending the calibration below 0.5 keV. The curve shown in Fig. 6 is a fit to our data using measured stripping cross sections with the effective length of the stripping cell a free parameter. The fit was obtained for $3 \times 10^{14} \text{ N}_2$ molecules/cm² or $L = 9.2$ cm at $P = 1.0 \times 10^{-3}$ torr.

In Fig. 7 the calibration factor $C(E) = \frac{1}{A\Delta\Omega} \frac{1}{\Delta E} \frac{I_0^g}{V}$ is plotted versus beam energy where $A = 0.71 \text{ cm}^2$, $\Delta E = 0.035E$, $\Delta\Omega$ is obtained from Fig. 4 and $\frac{I_0^g}{V}$ is obtained by the measurement procedure described previously. Our data extend up to 40 keV and were limited by the high voltage isolation of the ion source; however, the smooth variation of the data suggest that extrapolation to 100 keV would be reliable.

IV. Multi-Channel Analyzer Calibration

The multi-channel analyzer is calibrated by comparing the signal from the 2XIIB plasma on each channel in turn with the signal from the calibrated

analyzer tuned to the channel energy. The main advantages of this technique compared to direct calibration of the multi-channel analyzer are: (1) all of the initial calibration data over the full energy range are obtained with the same experimental apparatus; (2) it is simpler to periodically repeat the calibration of the single channel instrument on the atomic beam set up; (3) if a component of the multi-channel analyzer fails and must be replaced, the replacement can be cross-calibrated in situ against the single-channel analyzer; (4) the calibration of the multi-channel analyzer can be repeated on each data run of the experiment to verify stability of the calibration.

The channel energy is set by the

$$E_n = \left(\frac{H^2}{M} \right) \left(\frac{R_n}{144} \right)^2 \cot^2 \frac{\theta_n}{2} \text{ (electron Volts)}$$

where H is the field in the magnetic analyzer (in gauss), M is the mass number of the ion (assumed to be singly charged), R_n is the effective radius of the magnet pole piece and θ_n is the angle of deflection of ions entering channel n. R_n varies slightly over the different channels because of the influence of the fringing fields but is of the order of 15 cm. For a particular magnetic field setting, the momentum of particles entering the various channels is determined by the geometry of the analyzer. In our multi-channel analyzer, these channels are at intervals of 4.5° from $\theta = 18^\circ$ to $\theta = 54^\circ$ and then at 9° intervals from 54° to 108° .

Mass discrimination is obtained by passing the ions exiting the magnet at θ_n through a parallel plate electrostatic analyzer. Singly-charged ions will reach the detector when the voltage on this analyzer satisfies the relation

$$E_n = KV_n = \frac{H^2}{M} \left(\frac{R_n}{144} \right)^2 \cot^2 \frac{\theta_n}{2}$$

where K is the calibration constant of the electro-static analyzers determined

by their dimensions and identical for the sixteen channels of the system.

Calibration of the multi-channel analyzer involves two steps:

- Determination of the values of V_n (and thus E_n) for a selected value of H^2/M .
- Measurement of the ratio Y_n of the signal on channel n to the signal on the auxiliary analyzer when tuned to the same energy.

In practice we have found it convenient to plot the analog signal from the digital recorder of channel n against that of the auxiliary analyzer on an x-y recorder. The slope of this plot is Y_n which can be maximized by scanning V_n over a few cycles of the machine.

Since the signal on the auxiliary analyzer may be due in part to ions of different mass than that tuned to on the multichannel analyzer, it is necessary to estimate the fraction of the signal that is due to the ion of interest. This can be done by tuning the magnet field to the values set by

$$H^2/M = E_n \left(\frac{144}{R_n} \right)^2 \tan^2 \left(\theta_n/2 \right) = \text{constant for the various possible values}$$

of M and measuring $Y_n(M)$ for these settings. In the case of 2X the signal is mainly from the deuterium component with 10-20% hydrogen impurity. We assume that the signal on the auxiliary analyzer follows this relationship and define f_n , the fraction of the signal on the auxiliary analyzer due to deuterium by

$$f_n = \frac{Y_n(D)}{Y_n(D) + Y_n(H)}$$

V. Data Processing

The calibration data is used to generate a table of calibration factors

$$B_n = C(E_n) \cdot \frac{f_n}{Y_n(D) g}$$

where $C(E_n)$ is the value of the auxiliary analyzer calibration function at E_n , "g" is the gain factor of the auxiliary analyzer photomultiplier for the channel n calibration. f_n is the fraction of the signal on the auxiliary analyzer during the calibration that was due to deuterium and $Y_n(D)$ is the associated maximized ratio of the deuterium signal on channel n to the signal at the same energy on the auxiliary analyzer.

To interpret the signal from the plasma in terms of the ion energy distribution in the plasma, one must correct for the energy dependence of the charge exchange cross-section. The neutrals detected by the analyzer are produced by interactions between the energetic deuterium atoms of the neutral beams and ions moving normal to the beams. Consequently the relative velocity of the two particles is given by $v_n = \sqrt{\frac{2(E_n + \bar{W})}{M}}$ and the proper cross-

section value is $\sigma_n = \sigma(E_n + \bar{W})$ where $\bar{W}$ is the average beam energy.

The table of B_n 's and the matching table of $(\sigma v)_n$'s is incorporated in the reduction of the neutral analyzer data. Three quantities are calculated from the multichannel data as a function of time for each experimental pulse.

These are:

- 1) Fifteen-point energy distributions

$$f(E_n) = \frac{B_n}{(\sigma v)_n} S_n(t) \quad n = 1 \dots 15$$

where $S_n(t)$ is signal on channel n at time t.

- 2) Neutral flux

$$\begin{aligned} \Phi(t) &= \int \sigma v f(E) dE \\ &\approx 1/2 \sum_{n=1}^{14} [B_n S_n(t) + B_{n+1} S_{n+1}(t)] (E_{n+1} - E_n) \end{aligned}$$

3) Mean plasma ion energy

$$\bar{E}(t) = \frac{\int E f(E) dE}{\int f(E) dE}$$

$$\frac{1/2 \sum_{n=1}^{14} [E_n f(E_n) + E_{n+1} f(E_{n+1})] (E_{n+1} - E_n)}{1/2 \sum [f(E_n) + f(E_{n+1})] (E_{n+1} - E_n)}$$

A set of 4 processing programs have been developed¹⁴ which convert the data base into these physical quantities via energy distribution coefficient tables and average energy integration tables. The neutral analyzer table generator also sets up graphics tables for flux and average energy. Since these tables may be generated before an experimental pulse and are only changed when some setting of the multichannel analyzer is changed, the processing time for this data is quite short (8 seconds for 2000 points each of flux and average energy).

Processed data is recorded primarily on Tektronix 4012 graphics terminals with hardcopy attachments. Floating point lists of the energy distributions are also available and can be plotted or listed at selected times (to the nearest 10 μ s). Figs. 8 and 9 are examples of the average energy, flux, and distribution outputs.

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FIGURE CAPTIONS

1. General view of analyzer system.
2. Electrostatic analyzer and detector.
3. Auxiliary analyzer and calibration system.
4. Angular acceptance of auxiliary analyzer.
5. Observed full-width, half-maximum energy acceptance of auxiliary analyzer.
6. Stripping efficiency of auxiliary analyzer.
7. Auxiliary analyzer calibration factor $C(E)$.
8. Sample average energy and flux
9. Sample energy distributions.

Table I. Calibration Conditions

TABLE I

DEFLECTION PLATES	ANALYZER	SECONDARY SUPPRESSOR	CUP CURRENT	PRIMARY FUNCTION	GAS IN STRIP. CELL
ON	OFF	-	$I_1 = [f_0 I_0 + \epsilon' I_0] T$	MEASURE f_0, ϵ'	NO
ON	OFF	+	$I_2 = [\gamma_0 (1 - \epsilon') I_0 + \epsilon' I_0] T$	MEASURE I_0	NO
OFF	OFF	-	$I_3 = I_1 + [f_+ I_+ + I_+] T$	MEASURE I_+	NO
OFF	OFF	+	$I_4 = I_2 + [(\gamma_+ + 1) I_+] T$	MEASURE γ_+	NO
ON	ON	-	$I_5 = f_0 I_0 T$	MEASURE f_0	NO
ON	ON	+	$I_6 = \gamma_0 (1 - \epsilon') I_0 T$	MEASURE ϵ'	NO
ON	OFF	-	$I_7 = [\epsilon (1 + f_+) I_0 + f_0 (1 - \epsilon) I_0] T$	MEASURE ϵ	YES

GENERAL VIEW OF ANALYZER SYSTEM

FIGURE 1.

FIGURE 2.

AUXILIARY ANALYZER AND CALIBRATION SOURCE

FIGURE 3.

FIGURE 4.

FIGURE 5.

OBSERVED FULL-WIDTH, HALF-MAXIMUM ENERGY ACCEPTANCE OF
AUXILIARY ANALYZER

FIGURE 6.

FIGURE 7.

AUXILIARY ANALYZER CALIBRATION FACTOR $C(E)$

FIGURE 8.

SAMPLE AVERAGE ENERGY AND FLUX

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176-200	9.00	501-525	15.25
201-225	9.25	526-550	15.50
226-250	9.50	551-575	16.25
251-275	10.75	576-600	16.50
276-300	11.00	601-up	1
301-325	11.75		

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