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Observations of Secondary Emission Chamber Efficiency Degradation For Very High Intensity Slow Extracted Beams

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Degradation of Secondary Emission Chamber (SEC) efficiencies has been seen in the past[1]. As a result, instruments in use today are built to minimize any such effects. With beam intensities 5 times that which was incident on these devices in recent years we are again seeing significant degradation in SEC efficiencies. These effects began to become evident in last years SEB run[2] and this year they were studied in greater detail[3]. This report summarizes the observations that were made in FY95 SEB run.

1. **Introduction:**

The AGS uses secondary emission chambers to monitor beam intensity of the slow extracted beam. Beam currents for these beams vary from less than ½ uamp to over 2 uamp. Typically the beam is 1.2 to 1.6 seconds in length with intensities of 15 x 10^{12} (on target SEC's) to 60 x 10^{12} (on the C10 SEC, at the beginning of switchyard), protons per 3.2 to 3.6 sec pulse rate.

SEC's are located upstream of each of the primary beam targets and a single SEC is located at the beginning of the switchyard, just before CD1. Each device contains 5 successive parallel 1 mil silver plated aluminum plates.[4] Three of the plates are connected to a high voltage power supply and typically operate at 750 volts. A small titanium sputter ion pump (8 L/sec) located on top of the SEC box keeps each SEC at a vacuum of 10^{-9} to10^{-8} torr. Two of the plates are summed and the output goes into an I/F module which is adjusted to count 6500 counts per sec for 524 nA.

Last year the AGS hit very high intensities of 30 to 40 x 10^{12} ppp and it began to become evident that SEC efficiencies were degrading. In this years SEB run this degradation was studied more carefully. This degradation is most evident on the C10 SEC, which is exposed to the most intense beam. Degradation of all the SEC's is observed. One exception, though, is the B5 SEC which shows an enhanced efficiency where the beam is most frequently incident.

Various methods have been tried for calibrating the SEC's and all have relatively high uncertainties. Foil activations were done during last years SEB run and these typically have uncertainties of the order of 10 %. A new method was tried this year in which local losses are created in the switchyard and comparing inefficiency to efficiency, while transporting all the beam to a single beam line. This method also has an uncertainty of 10 - 15 %. The traditional method of transporting all the beam to a single beam line and tuning for as clean a transport as possible was performed three times this year, also yielding uncertainties of approximately 10 %. These uncertainties apply to the target SEC's, in which primary transport is made to be as clean as possible and not to the C10 SEC which can be calibrated accurately using the traditional inefficiency versus efficiency method. With this method we also had difficulties this year, since the SEC degradation is position dependent and the center of mass of the beam changes while making the measurement. For a uniform surface efficiency on the SEC, though, the device can be calibrated to within 2 % using this method (this calibration was attempted on 17 April 1995 but failed due to the degree of degradation in the SEC -- the center of mass of the beam moves while doing this calibration).

2. **Theory of Operation:**

SEC's are not complicated devices. There are no moving parts. If the vacuum is very good then ionization effects are negligible. In general the foil surfaces can be considered as electron emitters. This emission is generally independent of foil thickness, being a surface phenomena. Low energy electrons emitted from the plates are collected on consecutive voltage biased plates (which also collect electrons emitted from themselves). Other effects such as secondary emissions from higher energy electrons produced from Rutherford scattering do contribute to the signal for high energy proton beams. The most important characteristic of the SEC is its efficiency.

$$\rho_c = \frac{number \quad of \quad emitted \quad electrons}{number \quad of \quad incident \quad charged \quad particles} \; x \; 100 \; \%$$

which is a function of foil material, surface conditions of foil, chamber pressure, properties of incident particles, and the incident angle of the incident particles. In the case of thin low mass foils (such as aluminum) this efficiency is a linear function of the energy lost by the incident proton beam in the foil.

$$\rho = k \cdot \frac{dE}{dx}$$

For 24 GeV/c protons on aluminum , dE/dx is approximately 1.8 MeV g^{-1} cm^2 [5] . Typical efficiencies are of the order of 2.2 % per emitting surface. [6] The degradations which we observe are on the order of 20 to 30 %, which implies the efficiency, or the number of emitted electrons, has decreased by at least the same amount.

3. Some Results from 1995 SEB Run:

Figures 1 through 5 summarize the results of data taken during the 1995 SEB run.

Figure 1: Horizontal Response Scan of the C10 SEC; Efficiency versus position of the beam on the SEC. The scan clearly shows the degradation of the surfaces of the SEC. The data plotted shows the results of two scans, one performed in April and the other performed at the end of the SEB run (in June). Also plotted is the sum of the four long loss monitors subtending the AGS ring. The scan was made by changing the current in the F10 ejector magnet. Thus at the edges of the scan the losses shoot up quickly, corresponding to greatly mis-steered beam and beam being lost in the AGS ring. The scans to not overlap because the F10 was worked on between the time of the scans, giving a different range of currents by which we could adjust the power supply. The setpoint of the F10 was varied a great deal between the time of the two scans, to provide different sharing ratios, and also due to problems, or perceived problems, with the F10 P.S. Drifts in the beam sharing ratios were often corrected by adjusting the F10 P.S., which was also the suspected cause of the drifts, but they were also adjusted by changing the SEB splitter positions. Therefore the position of the center of the two scans could easily have changed. The scan done in June also shows the effect of beam losses upstream and near the SEC by a step in the efficiency at 30 mm.

Figure 2: Vertical Response Scan of the C10 SEC. In this case the beam position was moved using the F20 Vertical bump in the AGS, causing a vertical orbit distortion displacing the beam at the F5 through to the C10. The motion at the F5 septum was about 3

time greater than at the C10, causing the beam to scrap vertically on the septum. The lines drawn on the figure correspond approximately to the points at which the beam begins to hit the vertical apertures of F5.

Figure 3: Horizontal B5 SEC Response Scan. This data was presented in reference 2 but is presented here because of the unusual nature of the response. All other target SEC scans show the same basic character as the C10 SEC, a reduced SEC efficiency at the point most frequently hit by the beam. B5 SEC, on the other hand, shows an increased efficiency.

Figure 4: Vertical B5 SEC Response Scan.

Figure 5: C10 SEC Response versus integrated proton fluence per cm^2. The SEC efficiency can be seen to be dropping linearly with integrated incident beam at a rate of 0.2 % per 10^{18} p/cm^2. The data is taken from MCR Coordinator logs and is the ratio of C10 SEC to the internal current transformer just before extraction, plotted versus the integrated beam intensity divided by the area the beam is interacting with on the SEC. Variations in the curve would be due to beam targeting the SEC differently and due to variations in the extraction inefficiency.

Table 1 summarizes the calibrations of the SEC's for the run. The numbers shown are the multiplying factors needed to be applied to the existing calibration (which was kept constant for the entire run) to give the correct beam intensity. Therefore a larger multiplying factor implies a degraded response in the SEC.

Table 1: SEC Calibrations and Multiplying Factors

SEC	*Cal. Const.*	*1/95 Factor*	*4/95 Factor*	*6/95 Factor*
A	5.71e-04	0.96	0.94	1.04
B	6.50e-04	1.13	0.90	0.96
C	5.71e-04	1.05	1.37	1.51
D	5.71e-04	1.14	1.00	1.17

4. Simulation of SEC Scans:

In order to understand better the meaning of the SEC scans, and to derive some information about the character of the degraded spots, a simple simulation was done using Mathematica® (using the X-window version on the IBM RISC 6000 in CCD).

The simulation consisted of moving a 2-dimensional Gaussian 'beam' over a 2-dimensional Gaussian target, taking the product and integrating to obtain a single number representing the SEC output current (all normalized to give numbers in percent). Figures 6 - 8 summarize a typical run. In figure 8 the line represents the SEC surface efficiency and the points represent the integrated product of the two Gaussians for the beam centered at each point (thus simulating a scan).

What this simple simulation suggests is that for a scan in which the most degraded spot may show to be about 70 % of the normal response, the actual depth of this degradation is 40 %. Even a spot which has degraded to a depth of 0 % will only show a minimum response of 50 %. The June scan of the C10 SEC dropped to 70 % at the minimum, suggesting the actual response at this point is more on the order of 40 %.

5 Conclusions:

With very high proton beam intensities the SEC's prove to have a limited reliability, at least as an absolute intensity monitor. In the near future we need only be aware of this and try to correct for it as much as possible. But since we have yet to develop calibration techniques which we can trust to better than 10 % we cannot expect these devices to do more than act as relative and short term efficiency monitors.

We can calibrate the C10 SEC to as well as 2 % and for this reason having a calibration 'facility' near the C10 location should be seriously considered. An SEC calibrated at C10 and then placed in a target location, all other factors being equal, would be our most accurate method of measuring the transport efficiencies in the SEB. Calibrating all the SEC's in this way at the beginning of an SEB run would be best since we would then have a very well defined starting point, and it would also provide the least amount of radiation dose to personnel involved in the process.

There are still a number of unresolved questions. Do all the SEC's degrade at the same rate and how sensitive is this degradation to the techniques used in constructing the SEC's ? What is causing the degradation ? Understanding these questions is fundamental for developing a better SEC. Of course we should ask whether there could be a better method of measuring the intensity. Any nondestructive measurement is going to be very difficult to do, due to the low currents and the high electrical noise environments any such device and its electronics would have to contend with.

Two of the SEC's from the FY95 SEB, the B5 SEC, which showed an enhanced spot, and the CSEC, which was the most degraded of the target SEC's, are being removed and will be set aside to allow us to study them .

Acknowlegements:

Dan Lehn was very helpful in teaching me how an SEC is built and provided most of the specifications given in the introduction. Lief Ahrens, I Hung Chiang, Woody Glenn, and Andy Soukas were all excellent sources of technical and historical information on this subject.

References:

[1] Tests of SEC Stability In High Flux Proton Beams; V. Agoritsas, CERN and R.L.Witkover, BNL. IEEE Transactions on Nuclear Science, Vol. NS-26, No. 3. June 1979.

[2] AGS Studies Report No. 319, K.A. Brown. January 1995.

[3] AGS Studies Report No. 329, K.A. Brown. May 1995.

[4] AGS Assembly Drawing D11-M-18864-5

[5] Review of Particle Properties, Physical Review D, Particles and Fields v. 50 No. 3. August 1994.

[6] V. Agoritsas, CERN/MPS/Int. CO66-30 (unpublished report). June 1966.

FIGURE 1: C10 SEC RESPONSE vs POSITION ON SEC

BASED ON POSITION SEEN ON CF011 FLAG

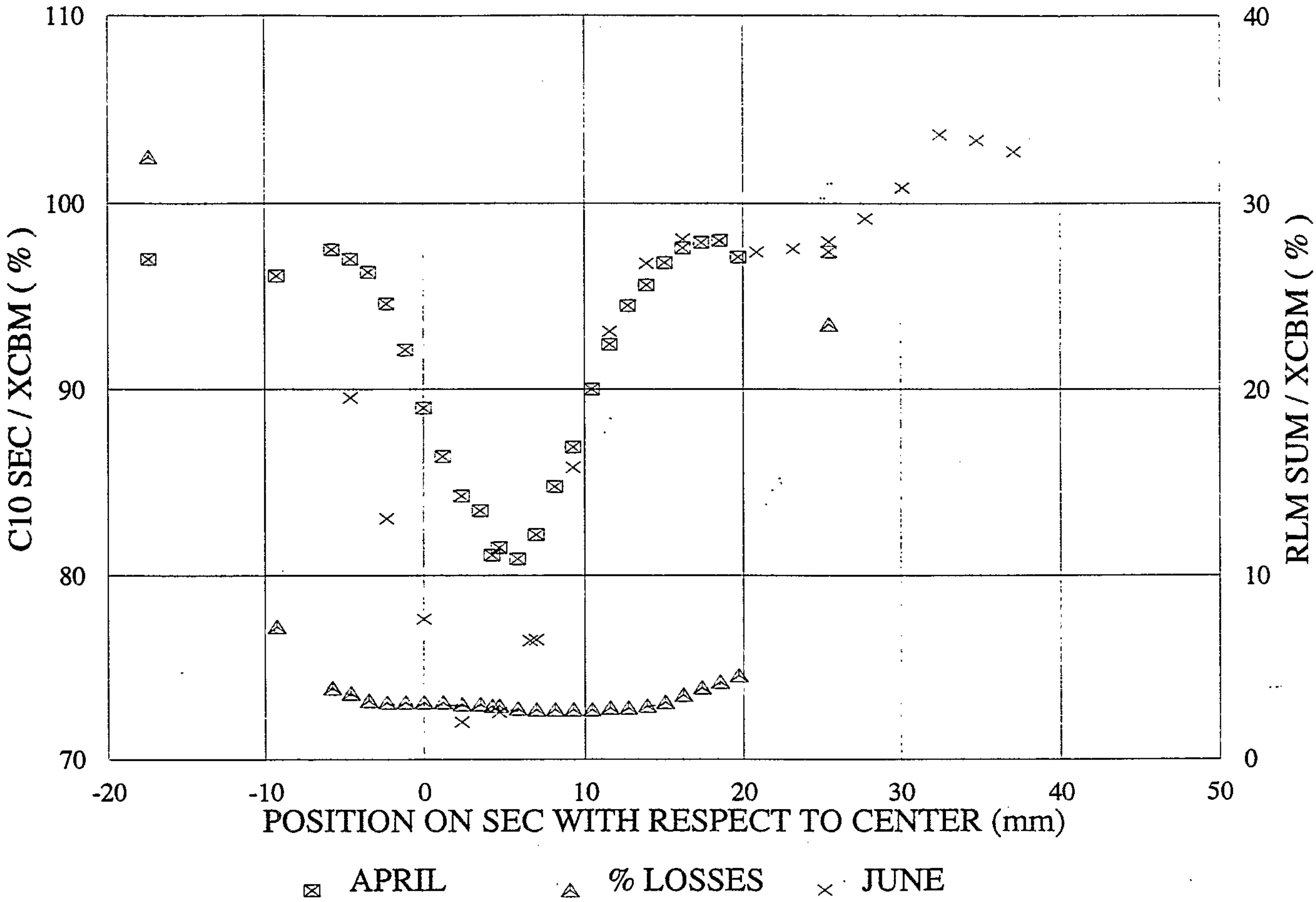

FIGURE 2: VERTICAL SCAN OF C10 SEC

SCANNED USING F20 VERITCAL BUMP

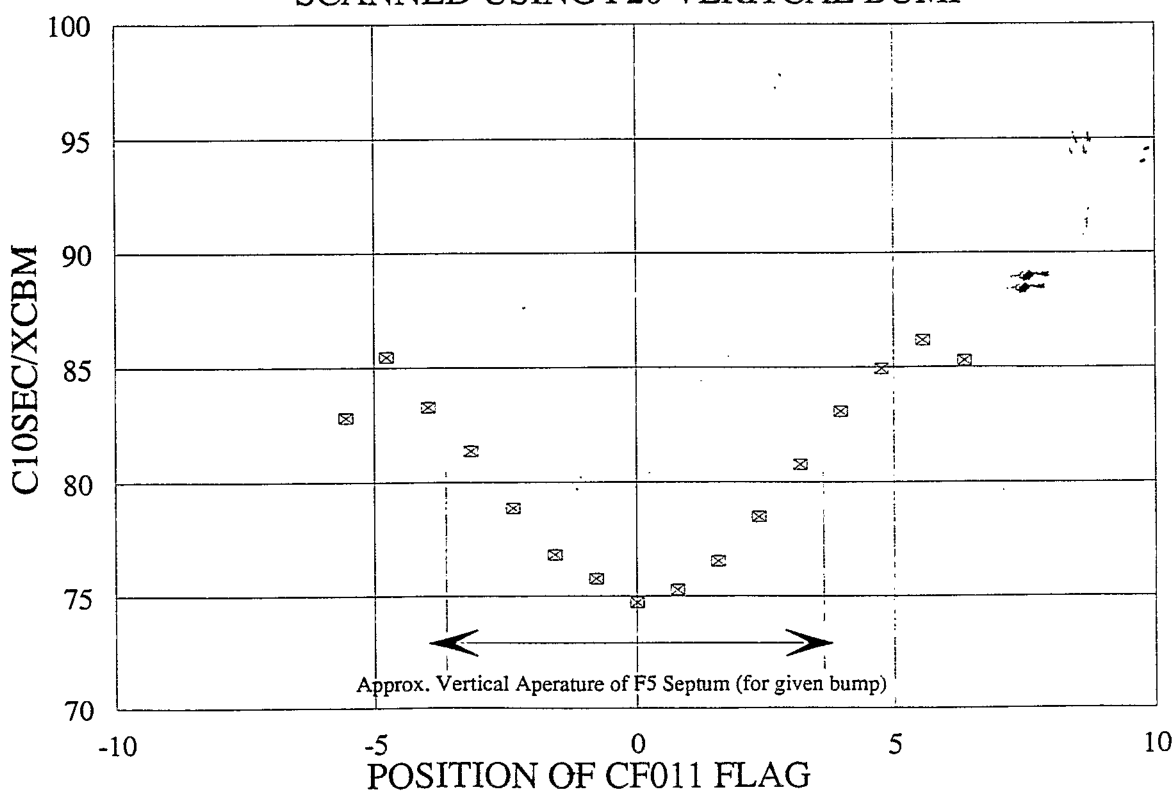

Figure 3: HORIZONTAL SCAN OF B5SEC

B5SEC and B5TEL vs Position on B5SEC

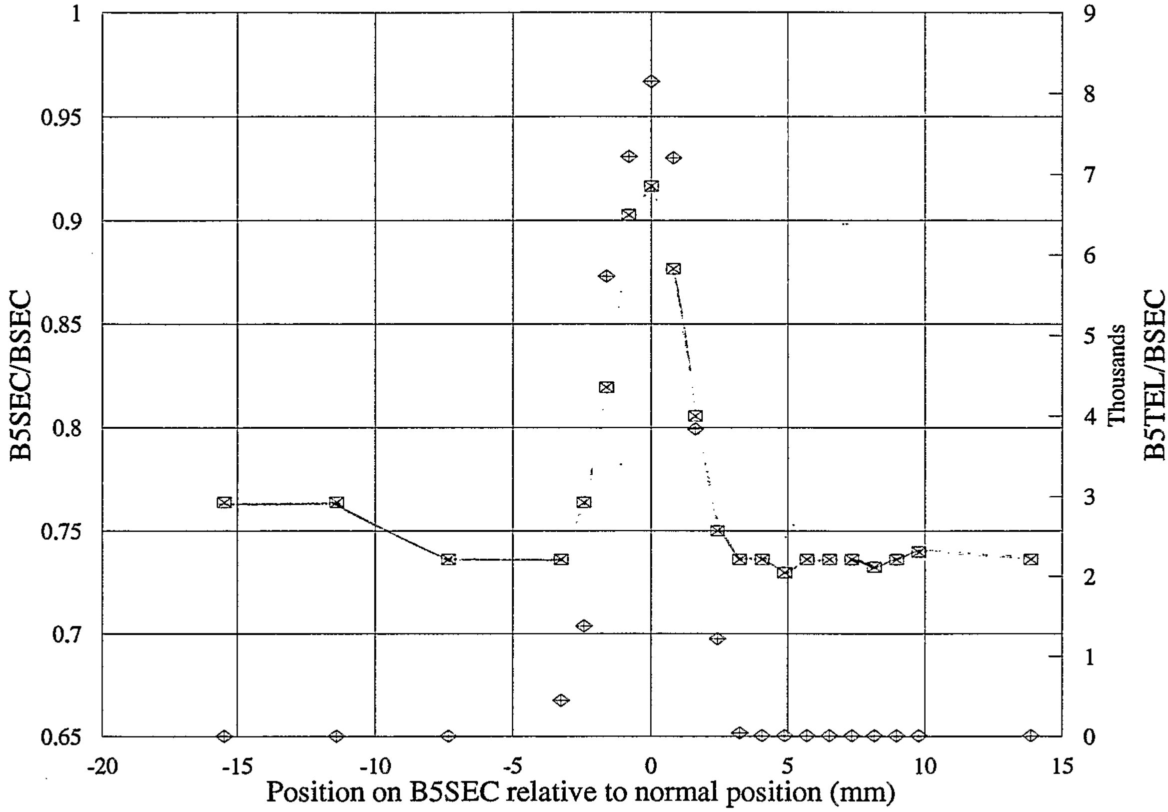

Figure 4: VERTICAL SCAN OF B5SEC

B5SEC and B5TEL vs Position on B5SEC

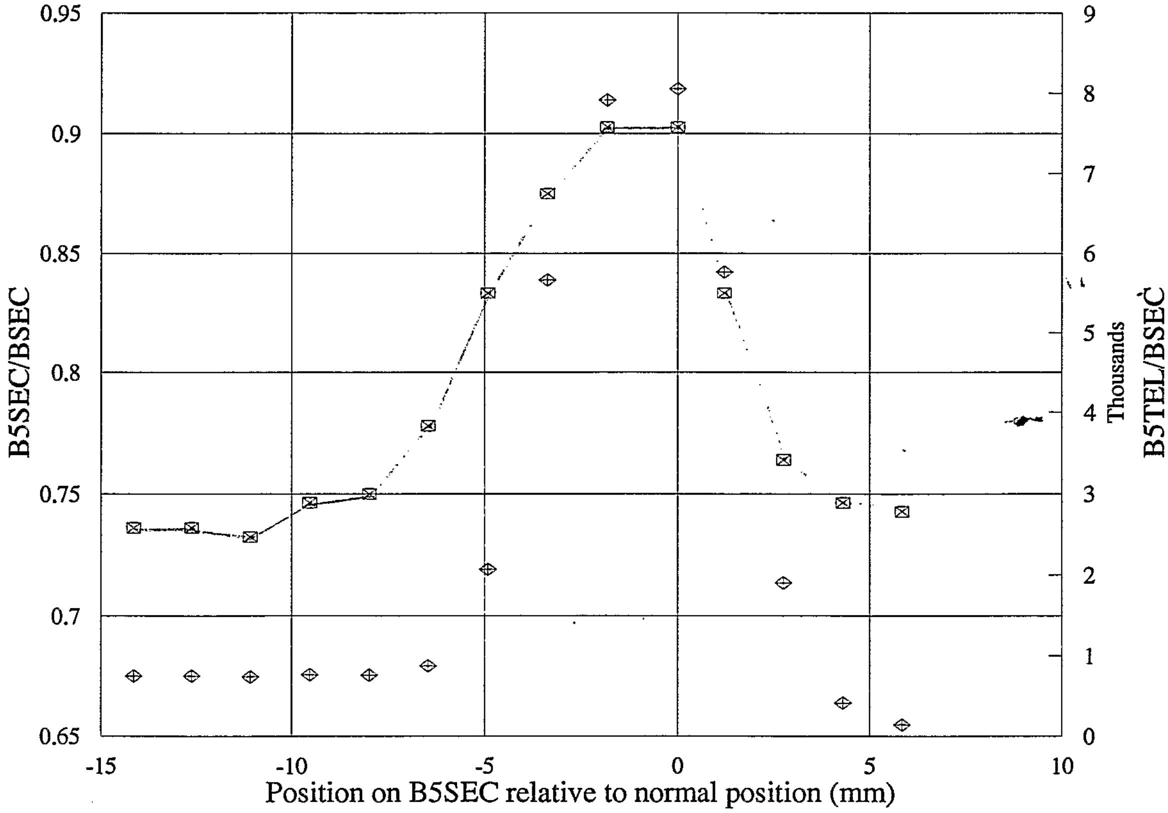

FIGURE 5: Degradation of C10 SEC

Per Integrated Incident Beam per Unit Area on SEC

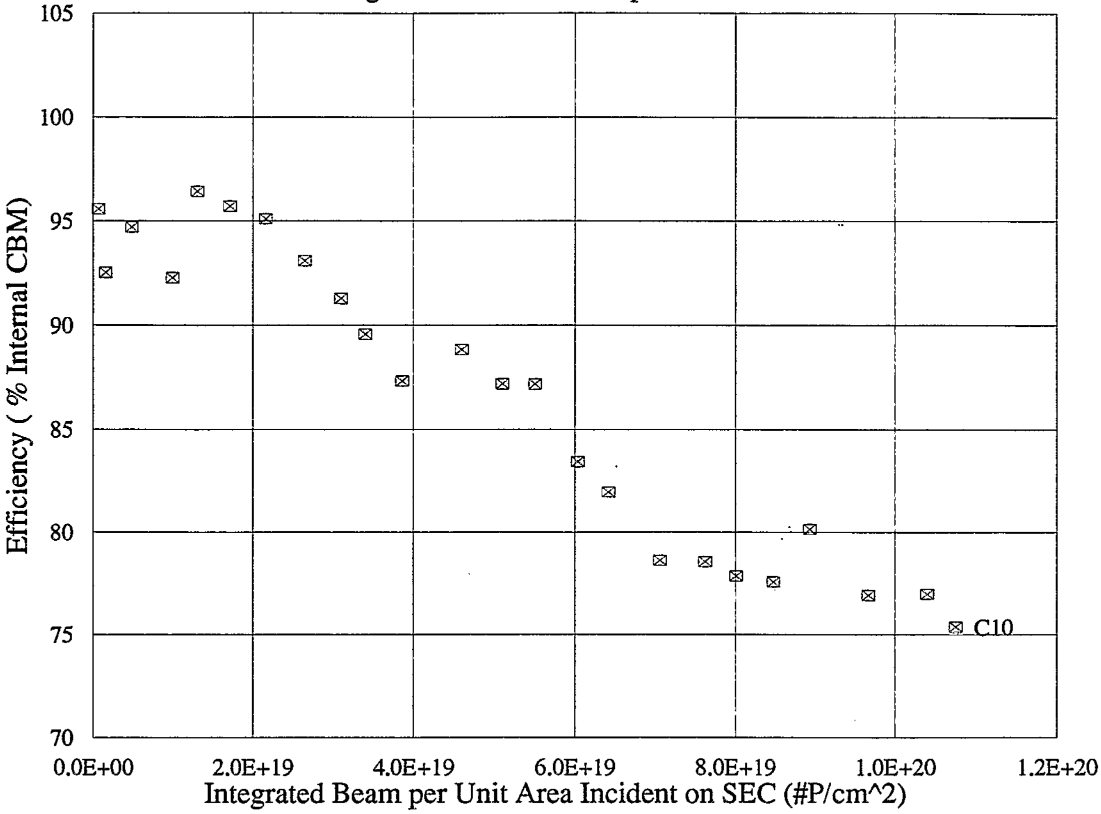

Figure 6: Simulated Beam on C10 SEC

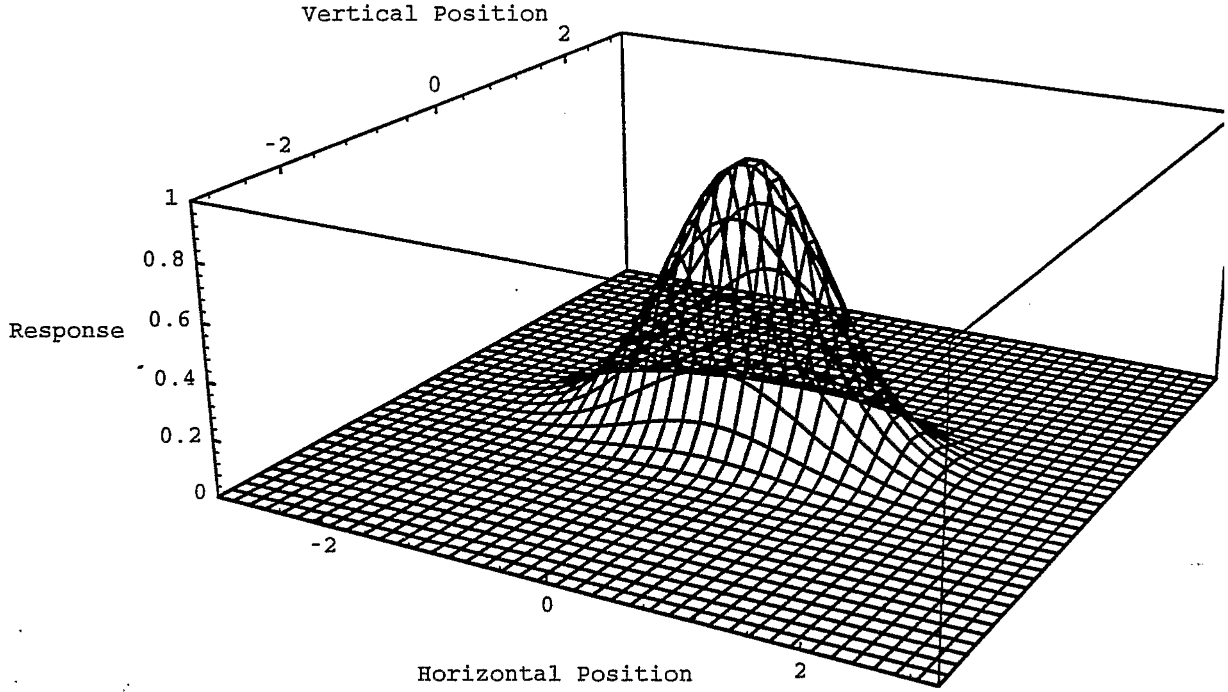

Figure 7: Simulated SEC Target Surface Response

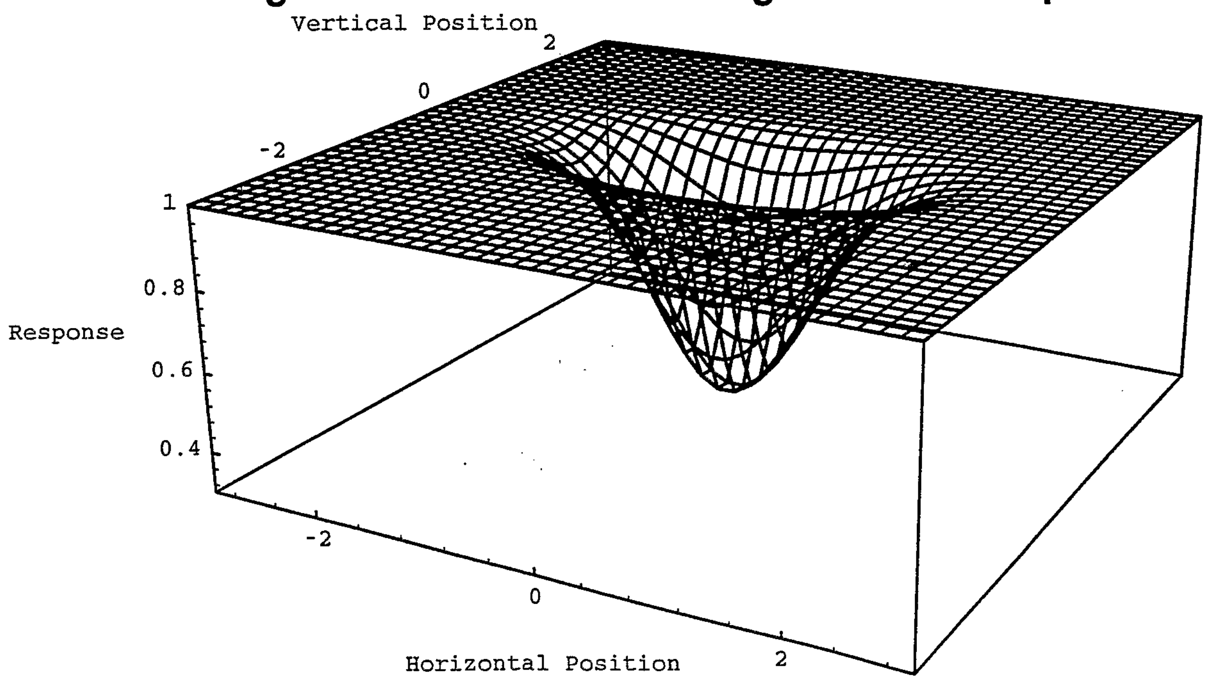

Figure 8: Simulated Scan of C10 SEC