SECONDARY EMISSION CHAMBERS

FOR MONITORING THE CPS EJECTED BEAMS

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ABSTRACT

The Secondary Emission Chamber (SEC) is a particle detector device which uses the phenomenon of electron emission from the surfaces of very thin metal foils bombarded by charged particles. The main merits of these detectors are that they are not saturable at high current densities and in many cases their interference with the beam structure is negligible.

Three different aluminium foil secondary emission chambers have been designed and constructed up to now for continuous monitoring of the CPS ejected beams during beam set-up and operation.

The report is divided into two parts. The first includes:

a) a general introduction to the device
b) a detailed description of the three secondary emission chambers
c) a simple description of the vacuum system used, and
d) a description of the charge measuring device.

The second part deals with the SEC performance tests and their use as continuous monitors of ejected proton beam intensity, as well as a beam control device. In the same chapter, the different methods of SEC calibration, both relative and absolute, are described and discussed.

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INTRODUCTION

A great need for reliable, non-destructive and continuous beam intensity monitors has been felt since the slow ejection technique was successfully tested. The circulating protons of the CPS can be ejected by two different methods, notably fast ejection and slow ejection. The properties and characteristics of the CPS ejected beams are summarized in Table 1. The general layout of the ejected proton beams around the CPS is shown in Fig. 1. The time structure of the fast and slow ejected beams is shown in Figs. 2 and 3 respectively.

The problem on hand was to monitor the above high-intensity, high-energy proton beams which had never been encountered previously in secondary beams around the CPS.

Ideally, the monitoring devices should provide a signal which is precisely proportional to the total beam current and involves negligible interference with the proton beam, so that the high-intensity beam can be monitored continuously during beam set-up and experiment. Unfortunately such general ideal monitors do not exist. That is why, for each particular beam, the most adequate monitor has to be used after weighing up the advantages and disadvantages.

One of the monitoring methods suggested for the CPS slow ejected beams is the SEC (SECONDARY EMISSION CHAMBER). We use this abbreviation instead of SEM (Secondary Emission Monitor), generally used in reports, in order to avoid confusion with SEM (Slow Ejection Magnet), which is part of the same beam.

SECONDARY EMISSION CHAMBER HISTORY

For many years, parallel plate transmission ionization chambers fulfilled the function of monitoring beams of charged particles satisfactorily. Ionization chambers are simple in concept and construction, but
<table>
<thead>
<tr>
<th>Type of ejection</th>
<th>Intensity (p/burst for (10^{12}) p circulating)</th>
<th>Burst length</th>
<th>Burst time structure</th>
<th>Flux density (p cm(^{-2}) sec(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Internal beam intensity: (5 \times 10^{11}) to (10^{12}) protons per pulse (shared between several users) repeated every 1 to 5 sec</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Proton momentum: adjustable from 10 to 25 GeV/c</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ejected beam cross-section: 0.1 cm(^2) at focus, several cm(^2) elsewhere in the beam (up to several tens of cm(^2) at final beam stopper)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast ejection</td>
<td>(5 \times 10^{10}) to (10^{12})</td>
<td>10 nsec to 2 (\mu)sec</td>
<td>1-20 bunches (~ 10 nsec width over 100 nsec each bunch)</td>
<td>(10^{16}) to (10^{20}) (10^{10}) to (10^{13})</td>
</tr>
<tr>
<td>Slow ejection</td>
<td>(10^{11}) to (5 \times 10^{11})</td>
<td>1-200 msec</td>
<td>Smooth low-frequency structure + RF</td>
<td>(10^{11}) to (10^{16}) (10^{10}) to (10^{13})</td>
</tr>
</tbody>
</table>
because of ionic recombination they become unable to collect all the ions produced in the chamber as the beam current density increases. Extension of the linear range is commonly achieved by reducing both the density of the used chamber gas and the inter-electrode distance.

The upper limit of linearity of a parallel plate ionization chamber seems to be around \(10^{14} \text{ p cm}^{-2} \text{ sec}^{-1}\). However, during earlier studies carried out by a number of investigators on the saturation of the ionization chamber, the secondary electron emission from the ionization chamber walls was first observed. The SEC was first designed, developed and used as such by G. Tautfest and H. Fechter early in 1955. Since then, although most nuclear physics laboratories possessing a particle accelerator have constructed their own SEC's, the use of SEC with intense proton beams has been limited. Thus, there is very little literature concerning SEC behaviour in high-energy, high-intensity proton beams.

### THEORY OF OPERATION AND PRINCIPLES OF CONSTRUCTION OF A SEC

When a charged particle passes through a thin foil of metal, its accompanying electromagnetic field interacts with the peripheral electrons of the foil surface atoms, as well as with the free electrons of the metal, providing some of them with enough energy to be ejected from the atoms and to escape from the surface.

Say \(E_i\) = the energy of a secondary electron received by ionization of the incident particle, there is emission if

\[ E_i > E_r + W \quad \text{where} \quad E_r \quad \text{such as} \quad R(E_r) > \Delta x \]

- \(W\) = work function of the foil material
- \(R(E_r)\) = range of the secondary electron in the foil material
- \(\Delta x\) = maximum depth below the surface from where secondary electrons can escape.
The phenomenon is very similar to the ionization process of a gas atom along the trajectory of a high-energy charged particle. The foil surface is then considered as an electron emitter. Another foil positively biased will collect these electrons and at the same time those emitted from the bias foil as well. The phenomenon is observed only if, between the emitting and collecting foils, a very high vacuum exists. Fig. 4 illustrates these principles of operation.

Bias curves of many SEC's indicate that the most probable energy of the escaping electrons is of the order of electronvolts (5 - 10 eV) and the maximum depth $\Delta x$ below the surface from where secondary electrons escape is of the order of $10^{-8}$ m $= 100 \AA$, i.e. $\sim 100$ atomic diameters. Therefore the secondary electron emission due to incident charged particles of high energy is a surface phenomenon independent of the foil thickness. We are, therefore, in the presence of the same phenomenon as that encountered with the secondary emission observed on metal surfaces when they are bombarded with electron beams of low energy (photo multipliers). These experimental facts are true, independent of the energy of the incident particles, providing that the velocity of the particles is much higher than that of the atomic electrons. It seems that the phenomenon is independent of the nature of the particle providing that its charge is equal to electron (positive or negative).

The above process of secondary electron emission is the most important and direct one, if the thickness of the SEC foils is of the order of $\mu$m. However, a small percentage of the phenomenon is due to the following indirect processes. We consider here protons of high energy as incident charged particles but the phenomenon is present with any type of charged particle of high energy.

1) A proton passing through a foil produces scattered electrons of $\delta$-rays due to Rutherford scattering. For thin ($\mu$m) aluminium foils the energy of the $\delta$-rays is of the order of 20 keV. This phenomenon depends on the foil thickness and proton energy. The bias voltage of the SEC is too low to influence the motion of these electrons. A large part of these knock-on electrons will be captured by adjacent foils, so that the direct contribution of these electrons is very small, to the SEC signal, but when they escape the foil or traverse an adjacent foil they will produce, in their turn, secondary emission in the same way as the protons do.
2) The beam protons interact as well with the nucleus of the foil atoms, giving rise to high-energy charged particles. They emerge from the mother foil and traverse adjacent foils, producing in their turn secondary electron emission on the surfaces of the foil as well as \( \delta \)-rays. It is well known that the number of interactions between protons and nucleus is a function of the foil thickness and the incident proton energy.

The contribution of these two processes to the SEC signal is 2 - 3\% \(^{1)}\) in a SEC of 20 Al foils of 5 \( \mu \)m thick with 19.2 GeV/c incident proton momentum. However, these two indirect processes' contribution to the secondary emission of low-energy or the so-called true secondary emission were recently found to be very useful for measuring the absolute target efficiencies working inside the circulating proton beam or in the ejected beams \(^{13}\) (details given in paper presented at this Conference \(^{39}\)).

The concept of a SEC is, therefore, simple, although the construction represents some technological difficulties. The problem of construction consists simply of isolating a number of very thin metallic foils inside a vacuum chamber ended with two thin windows. The foils are then alternately connected to a bias voltage or to a charge measuring device.

The secondary emission chamber is therefore a charged particle detector which can be used as a beam intensity monitor if correctly calibrated. Experimental results indicated that the SEC has a linear response for very high fluxes of incident beam of high energy electrons \(^{14})^{15}\).

SEC EFFICIENCY

The most important characteristic of a SEC is its efficiency or yield \( \rho \). SEC efficiency is defined as the ratio of the number of secondary electrons emitted over the number of charged particles which have passed through the foils of the SEC, generally expressed in percentages:

\[
\rho_e = \frac{\text{number of emitted electrons}}{\text{number of incident charged particles}} \times 100\%
\]

\(^{1)}\) see following pages
With reference to the previous paragraph, SEC efficiency is a function of many factors, which are mainly:

1) the nature of the SEC foil material as well as of the foil thickness
2) the surface conditions and chamber pressure
3) charged particle properties, mass, charge energy
4) the incident angle of the charged particles.

However, in the case where the incident charged particles are high-energy protons and the SEC foils are thin aluminium foils of thicknesses of the order of µm, the SEC efficiency per emitting foil can be written as

$$\rho = k \frac{dE_i}{dx}$$

where

- $k$ = constant of proportionality
- $\frac{dE_i}{dx}$ = energy loss per gr cm$^{-2}$ of the incident protons in the foil material.

In Table 2 we summarized the reported efficiencies of a number of SEC's against a number of other parameters of each chamber. An examination of the table shows that the reported SEC efficiencies differ greatly from one report to another, even for relativistic electrons and for similar SEC characteristics. We believe that the biggest part of this discrepancy is due to the incident beam charge determination, i.e. the SEC calibration method used in as well as to the emitted charge measuring technique and to the surface condition of each foil. With such a diversity of results, it is difficult to make comparisons and to make them fit with theoretical studies of the phenomenon. However, a number of reported studies are only qualitative and up to now no theoretical approach reproducing all the experimental observations of the secondary emission of low-energy electrons has been achieved. For instance, a theory developed by Aggson is compatible with experimental results. This theory explains satisfactorily the energy dependence on the SEC efficiency for high-energy electrons as incident particles.
Reported SEC Efficiencies

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Foil material</th>
<th>Thickness of foil</th>
<th>Mass (mg \text{ cm}^{-2})</th>
<th>Length in microns (10^{-3}) m</th>
<th>Number of emitting surfaces</th>
<th>Incident beam (e^-)</th>
<th>Energy (\text{MeV})</th>
<th>Over-all %</th>
<th>% per emitting surface</th>
<th>Calibration method</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Al</td>
<td>1.71</td>
<td>6.30</td>
<td>19</td>
<td>e^-</td>
<td>150.0</td>
<td>39.75</td>
<td>2.09</td>
<td></td>
<td>Faraday cup</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Al</td>
<td>5.40</td>
<td>20.00</td>
<td>19</td>
<td>p</td>
<td>591.0</td>
<td>36.00</td>
<td>2.84</td>
<td></td>
<td>'(^{14})C - '(^{14})C + ionis. chamber</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Al</td>
<td>5.40</td>
<td>20.00</td>
<td>19</td>
<td>p</td>
<td>591.0</td>
<td>36.70</td>
<td>1.83</td>
<td></td>
<td>Activation - calorimeter</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Al</td>
<td>1.62</td>
<td>6.00</td>
<td>6</td>
<td>e^-</td>
<td>230.0</td>
<td>12.00</td>
<td>2.00</td>
<td></td>
<td>Faraday cup</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Al</td>
<td>3.24</td>
<td>12.00</td>
<td>20</td>
<td>e^-</td>
<td>150.0</td>
<td>44.00</td>
<td>2.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Au + Al</td>
<td>15.66</td>
<td>24.8</td>
<td>6</td>
<td>e^-</td>
<td>204.0</td>
<td>22.00</td>
<td>3.00</td>
<td></td>
<td>Faraday cup</td>
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<tr>
<td>16</td>
<td>Au + Al</td>
<td>15.66</td>
<td>24.8</td>
<td>6</td>
<td>e^-</td>
<td>215.0</td>
<td>24.00</td>
<td>4.00</td>
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<tr>
<td>17</td>
<td>Al</td>
<td>1.4</td>
<td>5.28</td>
<td>3</td>
<td>e^-</td>
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<tr>
<td>18</td>
<td>Al</td>
<td>3.80</td>
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<td>2</td>
<td>e^-</td>
<td>7.5</td>
<td>4.00</td>
<td>2.00</td>
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<tr>
<td>19</td>
<td>Al</td>
<td>2.50</td>
<td>7.62</td>
<td>2</td>
<td>e^-</td>
<td>30.0</td>
<td>5.00</td>
<td>2.50</td>
<td></td>
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</tr>
<tr>
<td>20</td>
<td>Au</td>
<td>2.62</td>
<td>10.00</td>
<td>2</td>
<td>e^-</td>
<td>2.00</td>
<td>4.35</td>
<td>2.17</td>
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<td></td>
</tr>
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<td>21</td>
<td>Al</td>
<td>1.51</td>
<td>5.60</td>
<td>2</td>
<td>e^-</td>
<td>1.6</td>
<td>3.15</td>
<td>1.57</td>
<td></td>
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</tr>
<tr>
<td>22</td>
<td>Al</td>
<td>3.43</td>
<td>12.70</td>
<td>2</td>
<td>e^-</td>
<td>200.0</td>
<td>4.00</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Al</td>
<td>1.73</td>
<td>6.40</td>
<td>2</td>
<td>e^-</td>
<td>30.0</td>
<td>2.70</td>
<td>1.35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Al</td>
<td>2.70</td>
<td>10.00</td>
<td>2</td>
<td>e^-</td>
<td>8.0</td>
<td>7.00</td>
<td>1.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Al</td>
<td>1.62</td>
<td>6.0</td>
<td>16</td>
<td>e^-</td>
<td>1.5 GeV</td>
<td>51.01</td>
<td>3.23</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

N.B. Over a beam energy range of about 1-600 MeV the variation of efficiencies with beam energy is similar to that for electron stopping power (energy loss).
SEC efficiency is expected to increase up to saturation with increasing collecting foil bias. However, contrary to this, experiments have shown that the efficiency has a maximum at about 30 - 50 volts. It is believed that the observed phenomenon is due to the so-called Malter effect 15) 21).

Malter 40) observed that an aluminium oxide surface coated with a monolayer CsO₂ gave very large values of ρ, values up to one thousand times that of normal aluminium. These secondary emission efficiencies were strong functions of the primary current. The phenomenon was persistent for varying periods after the primary current was removed. This Malter effect has been observed with several other metals with insulating films and it exists for oxide-coated aluminium without the monolayer CsO₂. Malter's accepted explanation of this effect is that the outer surface has an intrinsic value of ρ greater than one and since it is an insulating material this caused it to acquire a strong positive potential which can extract electrons from the metal by means of field emission.

THE CONSTRUCTED SEC's

A survey of secondary emission chambers as monitors of high intensity beams was undertaken before a decision was made to design and construct a SEC for monitoring the CPS slow ejected proton beams 24).

The conception, design and construction of the first SEC was based on two imposed conditions:

1) the overall mass of the SEC foils and windows had to be kept to a minimum in order to avoid much interference of the monitor with the beam optics during normal operation. This condition determined the overall dimension of the SEC, foil material and window material;

2) the SEC had to be bakeable, which helps degassing for obtaining high vacuum and clean surfaces;

3) the SEC had to present good resistance to radiation damage.
Experience gained from the construction and use of the first SEC helped us later to construct two other different SEC's. The following paragraphs describe the construction of the first in detail and the main characteristics only of the other two. Table 3 summarizes the main characteristics of the three constructed SEC's. We distinguish one model from another by the number of foils, for instance SEC 5 designates the SEC with five foils, etc.

SEC 5

This is a five aluminium foil SEC, three foils connected to the bias voltage (~+500 volts) and the other two connected to the charge measuring device. Its useful window diameter is 62 mm. The thickness of each foil is 5 µm, equivalent to 1.35 mg cm⁻². It was constructed in 1965 and since that time has been in operation in either the e₂ or e₃ beams of the CPS. In the e₂ beam both fast and slow ejections were used alternately.

Fig. 5 illustrates schematically the mechanical construction and dimensions of SEC 5.

1. The chamber and its windows

The chamber consists of a specially flanged stainless steel cylinder. The flanges at the two ends are home-made, all metal, gasketed by the window foils themselves. These window foils are stainless steel, each 25 µm thick, equivalent to ~20 mg cm⁻². For details of the window flange see Fig. 6. The window foils, tightened between two metallic surfaces, one flat and the other slightly curved, make the vacuum sealing. In order to ensure uniform tightening all around the window foils, 24 bolts, 8 mm ø, are used. The inner part of the window flange is shaped suitably to allow for curvature of the window foil. The bolts are generally tightened about 3 or 4 mkg torque. We can say that this flange is of a separable type, but up to now a new window foil is fitted each time the flange is opened and reassembled. No leak was found after a 200°C bake-out applied
Table 3

Characteristics of the three constructed SECs

<table>
<thead>
<tr>
<th>Model or name</th>
<th>Number of foils</th>
<th>Nature and thickness of each foil</th>
<th>Nature and thickness of the window</th>
<th>Total thickness mg cm$^{-2}$</th>
<th>Useful diameter</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>Emitting</td>
<td>Al 5 $\mu$m</td>
<td>stainless steel 25 $\mu$m</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEC 5</td>
<td>5</td>
<td>2</td>
<td>Al 5 $\mu$m</td>
<td>stainless steel 25 $\mu$m</td>
<td>45</td>
<td>62 mm</td>
</tr>
<tr>
<td>SEC 20</td>
<td>21</td>
<td>10</td>
<td>Al 5 $\mu$m</td>
<td>&quot;</td>
<td>69</td>
<td>120 mm</td>
</tr>
<tr>
<td>SEC 40</td>
<td>41</td>
<td>20</td>
<td>Al 5 $\mu$m</td>
<td>&quot;</td>
<td>109</td>
<td>62 mm</td>
</tr>
</tbody>
</table>
to the chamber over four days. The chamber components are chosen to withstand bake-out temperature of the order of $400^\circ C$. However, we have never gone higher than $200^\circ C$ up till now. Some other methods of joining the windows were tested but without success. Two pairs of vacuum connections are welded directly onto the chamber cylinder. An opposing pair has ceramic feed-throughs connecting electrically the signal and bias SEC foils respectively. Of the other pair, one forms the vacuum connection, the other is foreseen as a vacuum gauge connection. In these vacuum connections, the U.H.V. transitions are assured by using the Conflat type flanges.

2. The foils

All the internal parts of the SEC are assembled on a stainless steel ring, part of one side of the SEC window flange. On this ring, six stainless steel bars are screwed, serving as passive supports of the foil assembly. The five aluminium foils of 5 micron thickness are mounted on circular stainless steel frames. These frames consist of three rings which, when assembled, hold the foils tightly. The three parts of the frame are shown in Fig. 7. The assembly of the foils on the frame is a difficult job. A special metallic matrix was devised and constructed in order to keep to a minimum the number of destroyed aluminium foils. (The cost of each foil is approximately 100 Sw.frn.). Isolation of the foils between themselves and the bars is assured by special glass-cut washers and glass tubes respectively. The choice of glass as isolator was due to its abundance on the market and its good resistance to radiation damage, as well as to its low degassing rates. A small pressure in the whole assembly of the frames in all the bars is assured by a small spring adjusted by a screw at one end of each bar (see Fig. 6). The electrical interconnection of each foil frame and the corresponding feed-through is completely mechanical and free from soldering. For details see Figs. 6 and 8.

The total mass of the SEC 5 introduced in the beam is $\sim 45 \text{ mg cm}^{-2}$, due to the windows and target foils. Then the RMS projected angle due only to multiple Coulomb scattering of 20 GeV/c protons is about $4 \times 10^{-2}$ mradians.
Based on the experience of the first chamber, a second one was designed and constructed. In this SEC the useful window diameter is 120 mm and has two functions. One is the continuous monitoring of the proton beam intensity. This is achieved by an assembly similar to that of SEC 5, consisting of twenty-one 5 micron thick aluminium foils alternately connected to bias voltage or charge measuring device. The other function is an automatic indication of the relative radial beam position and dimensions with reference to the centre of the SEC. This is achieved by a concentric assembly of twenty extra 5 µm Al foils of an annular shape. Indeed, the second set of foils is similar discs with a concentric hole of 40 mm diameter. If the proton beam passes entirely through this hole no signal appears of the second set of foils. Each time the beam is deviated or defocused enough and part of the whole beam passes through the annular-shaped foils; the signal compared with that of the first set gives a clear idea of the beam radial position or beam defocusing. The SEC 20 consists of two cylinders each one ended by a 25 µm stainless steel window mounted in the same way as the windows of SEC 5. The two cylinders are vacuum tightened by using a Conflat type flange. The whole foil assembly is fixed in one cylinder. On the same cylinder, all the vacuum and electrical connections are welded. This type of construction permits opening the SEC without touching its two windows. Figs. 9 and 10 are photographs of SEC 20 parts.

The total mass of SEC 20 introduced in the beam, due to the windows and the 21 target foils (first function) is ~ 69 mg cm⁻².

SEC 40

This SEC was specially developed for use inside the PS ring areas of the ejected proton beams. It consists of forty-one 5 µm thick Al foils; twenty-one of them connected to the bias voltage and the other twenty to the charge measuring device. In reality the latter are divided into two groups of ten emitting foils each in order to study the influence of the
foil mass on the proton beam as well as the influence of the first half SEC on the second half SEC. Repetitive measurements indicated that the second half SEC gives 2% higher signal than the first half under the same conditions and for 19.2 GeV/c proton momentum. The PS ring areas are very bad experimental areas because of the very high radiation levels that exist there as well as the large number of electronic noise sources. We mention the most important ones:

1) radio frequencies (electromagnetic fields of accelerations, Linac, PS and RF particle separators)
2) variable or constant magnetic fields with or without ripple
3) magnetic fields due to power supply cables, and
4) induced radiation and accidental losses of beam.

Some of these noise sources are present in the ejected proton beam areas outside the ring but of lower levels. We therefore purposely increased the number of foils in order to obtain a good signal-over-noise ratio. Fig. 11 is a photograph of the device installed 1 metre in front of the $^3$He target of the $^3$He slow ejected beam. The mechanical construction is identical to SEC 20 and its useful window diameter is 62 mm. The total mass of this SEC is $\sim 109$ mg cm$^{-2}$.

THE VACUUM SYSTEM

We have already mentioned that the phenomenon of secondary emission of thin foils is entirely a surface one. One of the influential factors on SEC efficiency is the condition of the foil surface as well as the foil material itself. Large SEC efficiency drifts are observed each time a SEC is opened to air and pumped again later $^{11}$ $^{12}$ $^{14}$ $^{15}$ $^{16}$ $^{20}$ $^{21}$ $^{22}$ $^{23}$; vacuum dirtiness has a considerable influence on SEC efficiency.

For instance, in a vacuum system using diffusion pumps, the presence of the pump oil vapour inside the chamber is inevitable. Therefore in such a vacuum system there is an unavoidable oil deposit on the surface of the foils and the chamber walls, mixed with other dirt, which radically changes the condition of the foil surface. In view of these considerations, a dry vacuum system was adopted. Fig. 12 shows schematically the SEC and
its vacuum system. Apart from these considerations, two more characteristics are worth mentioning: the life of the vacuum system is very long and it is free from maintenance.

The vacuum system consists of three main parts:

1) an 8 L sec\(^{-1}\) T-type ion pump directly connected to the chamber by means of a welded stub-pipe, 40 mm diameter, of sufficient length to avoid interference of the magnetic field of the ion pump permanent magnet, with the free motion of the secondary electrons, which are of very low energy; the major components of the VacIon pump system are control unit (i.e. HT power supply and current indicator, which with reference to a chart, pressure indication is obtained), permanent magnet and ion pump. This ion pump is a "titanium sputter" type. The pump consists of an enclosure containing an anode grid made of stainless steel, sandwiched between two cathode plates made of titanium. Pumping is initiated by a suitable voltage between anode grid and cathode plates (negative polarity). Free electrons (there are always free electrons), tending to flow to the anode, are forced into a spiral path by the presence of a strong magnetic field. The greatly increased electron path length results in a high probability of collision between free electrons and gas molecules. These collisions produce gas ions and more free electrons. The gas ions then bombard the titanium cathode plates. In this process titanium atoms are knocked out of the plate. The sputtered titanium atoms are deposited on the anode grid forming chemical stable compounds with the active gas atoms, such as oxygen and nitrogen. Chemically inert gas is also removed by ion burial in the cathode and by entrapment on the anode. Because each collision produces an increasing number of electrons with long effective path lengths, pumping action is maintained down to very low pressures (less than 10\(^{-9}\) Torr). The built-in Tee in the 8 l/s VacIon pump provides two ports; one is used for roughing the pump down to its starting pressure (~10\(^{-2}\) Torr) through a suitable value and the second is available to be sealed to the secondary emission chamber, avoiding extra connection hardware.

2) A bakeable all-metal right-angle valve.

3) A Vac-sorb roughing pump. Pumping action of the Vac-sorb pump is achieved through the process of physical adsorption. When a gas comes into equilibrium with a surface, a certain quantity of gas is held or adsorbed on the surface by weak electrostatic forces of attraction known as Van der Walls forces. The capacity of the surface for adsorbing molecules of a particular gas is greatly increased when the surface temperature approaches the liquefaction temperature for the gas. This capacity is also proportional to the surface area. This is achieved by the use of highly porous absorbed materials.
A sorption pump consists basically of a vacuum-tight enclosure containing an adsorbant material, type 5A Molecular Sieve, a synthetic zeolite manufactured by Linde Co. To evacuate a system, the pumping action is initiated by immersing the sorption pump in a container of liquid nitrogen.

In choosing this type of roughing pump, the same factors were taken into account, as well as the other advantages, such as simplicity of operation, small dimension, small weight, absence of maintenance and absence of power supply.

Any time long degassing processes and leak detection were undertaken using diffusion oil pumps, care was taken to eliminate any emanation from the pump to the chamber by using liquid nitrogen traps.

THE SEC CHARGE MEASURING DEVICE

The SEC is considered as a charge generator. The charge produced on the emitting foils is distributed in time as is shown in Figs. 2 and 3. The signal is positive if the SEC bias is positive. In this case the foils are emitters of secondary electrons. With negative bias the signal is negative and the foils are collectors of the secondary electrons. In general, a positive bias is used. The SEC signal levels are reproducible and linear, only in the case of a very well focused beam free of associated halo of relatively big dimensions. If the beam itself or the beam halo only hits the foil frame or the chamber walls, the SEC signal increases a lot. This is due to the increased number of secondary particles present which in their turn produce low-energy secondary electrons. A charge measuring device had to be constructed which would measure the SEC charge accurately and provide signals in an adequate form for the Main Control Room of the CFS, as well as to the users of the ejected beam \(25a\). In addition to this the charge measuring device had to provide a signal for each machine cycle and be equipped with a variable-in-length gate. The SEC charge produced per foil is \(\sim 2.5\%\) of the traversing high-energy proton charge so that for the SEC 5 the maximum expected charge to be measured is of the order of \(10^{11}\) electronic charges, i.e. \(\sim 10^{-8}\) Coulombs. This tiny charge surge is distributed over 200 msec in time length for the slow ejected proton beam and only 2 µsec for the fast
ejected proton beam. The charge measuring device in our case is a home-made gated electrometer amplifier. The main part of the electrometer is a solid state differential amplifier, namely the Philbrick SP2A.

The principle of operation of the electrometer is explained with reference to Fig. 14.

The distance between the SEC location and the charge measuring device is of the order of 20 - 100 metres. A 75Ω low-loss double screened coaxial cable is used for the SEC signal transport which has an intrinsic capacitance, of the order of 60 pF m⁻¹, i.e. 1000 - 6000 pF stray cable capacitance, added to 500 - 1000 pF of the SEC plates themselves and the 50,000 pF storage capacitance of the charge measuring device. The first screen of the coaxial cable is floating on both sides and the second is grounded only at the electrometer end. We came to this arrangement after trial and error for a maximum signal-to-noise ratio. This total capacitance of the input circuit of the electrometer limits the build-up voltage due to the SEC charge to low levels. The SEC signal coaxial cable is terminated by 75Ω resistance during the whole time of the machine cycle minus the gate time length. This permits keeping the coaxial cable discharged and clean from any noise signal outside the gate time. The "Gate" of the electrometer is simply an electromagnetically operating change-over dry reed relay RL1. The SEC charge burst is then switched to a high quality condenser of 50,000 pF by actioning the dry reed relay through a 75Ω resistance to avoid reflections. The time length of the "Gate" open covers the length of the proton burst. The "Gate" is operated at the right moment and synchronized with the PS timing of the machine cycle.

Therefore the first operation of the SEC signal is to transform the SEC charge to an analogue voltage level build-up on the storage condenser, i.e. the condenser is used here as a rapid analogue memory. The condenser itself could retain this charge for hours, but the built-up voltage must be sensed by some means and the read-out circuitry will consume some current, slowly discharging the condenser. It is imperative then that the sensing device draw as little current as possible. A solid state differential amplifier of \( \leq 10^{11} Ω \) dynamic input impedance when connected
as an electrometer amplifier is used as sensing device. The discharge
time constant is then ~ 5000 sec!1 This long time constant permits a
successive accumulation of SEC charge surge of many machine cycles. The
output of the electrometer of 10 kΩ impedance is then digitized and a
train of pulses distributed to the MCR and beam users 25b). The digi-
tization is done in less than 20 msec. The electrometer amplifier is reset
for each machine cycle by actioning a second dry reed relay RL2, which
earths the electrometer input after the condenser was sensed. The wave-
forms of Fig. 14 indicate clearly the different transformations of the SEC
signal.

The overall arrangement keeps the charge measuring device input,
the storage condenser, the signal transformer coaxial cable and the emitting
foils of the SEC to almost ground potential. This technique reduces to
a minimum the effects of leakage due to ionization and atmospheric condi-
tions. However, the lower limit of voltage that can be sensed with 1% accuracy is of the order of 2 - 3 mV. This level is determined by contact
potential, difference of temperature, metallic potentials and to induction
type potentials. The lower limit of charge bursts that can be measured
with acceptable accuracy is of the order of 10⁻¹⁰ Coulomb per machine cycle.

New electrometer circuits are under development and preliminary
results are promising. Unfortunately we are obliged to keep the relay
type Gate so we still have troubles with the relay contact potentials.
The relay type Gate has another disadvantage: the inertial delay on the
"make" contact which is about 1 - 2 msec.

SEC PERFORMANCE AND DISCUSSION

The reported SEC performance is that of SEC 5. However, no
discrepancy was observed between the SEC 5 performance and the results
obtained later with the other two SEC's, namely the SEC 20 and SEC 40.

Fig. 15 shows the location of SEC 5 in the e₂ ejected proton
beam during the performance measurements 26). In Fig. 16 the complete
layout of the large-angle proton - proton scattering experiment is shown 27).
A good vacuum was maintained during all these measurements, \( \sim 10^{-9} \) Torr. Unfortunately the SEC does not provide voluntary change of vacuum and we did not manage to test the pressure dependence of the SEC efficiency. However, later tests with the SEC 20, which started to operate under bad pressure due to high degassing rates, showed a decrease of SEC efficiency against better vacuum up to \( 10^{-6} \) Torr; no further decrease was noticed. The indication of the vacuum pressure is the ion pump current itself. During bombardment of the SEC foils, the ion pump current was increased by a factor ten and even more in cases where the beam was hitting the chamber walls as well as the foils support and isolators. This increase of the ion pump current we believe was due to an increase of the degassing rates of the SEC surfaces. Anyhow, this ion pump current increase rendered a rough indication of the beam dimensions or its position with reference to the SEC geometric axis.

Most of the performance tests were done by using as relative indication of the proton beam intensity the reading of a counter telescope looking at the external \( \text{H}_2 \) target eight metres behind the SEC. The beam was continuously monitored on a scintillator screen installed after the \( \text{H}_2 \) target for good beam shape and position.

a) SEC bias curve

Fig. 17 shows the SEC efficiency against SEC positive as well as negative bias in volts. SEC efficiency goes up very rapidly presenting an insignificant overshoot at \( \sim 20 \) volts for the positive bias and a similar one at \( \sim 0.5 \) volt for the negative bias. We believe that this discrepancy is due to the measuring method. An excellent plateau is often reached for both positive and negative bias as high as \( \pm 2.5 \) kV. A bias of +500 volts is generally used for normal operation. Fig. 18 shows:

1) the first derivative of the SEC bias curve (position bias only);
2) the energy spectrum of the secondary electrons emitted from aluminium foils bombarded by relativistic electrons;
3) the energy spectrum of the secondary electrons emitted from aluminium foils bombarded by very low-energy primary electrons (100 ev).
The similarity of the three curves obtained under completely different conditions is excellent. These curves are in excellent agreement with theoretical studies of the phenomenon 31).

b) SEC efficiency against incident proton spot position

For this test the SEC was installed on a remote-controlled support (beam scanner). The SEC could then scan the beam horizontally and vertically and Fig. 19 shows the SEC efficiency against the proton spot position. There is very little variation of SEC efficiency over the whole useful foil surface. The signal increases tremendously if part of the proton spot hits the foil support or the SEC vacuum chamber walls. There is about $\pm 2\%$ SEC efficiency discrepancy between the position where the proton spot has hit the SEC foils for a long time and the SEC efficiency of the rest of the foils. However, less discrepancy was observed in later tests with the SEC 5. In this case the beam spot position on the SEC foils was controlled by beam gymnastics! We believe that this kind of discrepancy on the SEC efficiency is due to a kind of surface fatigue, for instance the bombard of the foils helps degassing. Simultaneously with this measurement an extra aluminium foil was irradiated and Fig. 20 is a radio-photograph of this foil, showing the proton beam cross-section form and dimensions. As a matter of fact, this picture corresponds very well to what can be found out by observing the horizontal and vertical scanning curves and taking into consideration the useful diameter of the SEC 5 window (62 mm) (see Fig. 19).

c) SEC efficiency linearity

Fig. 21 shows the linearity of the SEC efficiency against the incident protons determined here by the p - p scattering experimenters for a slow ejection mode 27). Discrepancies observed $\approx 1\%$. Fig. 22 shows the linearity of the SEC efficiency against the incident protons determined by the induction type monitor 32) for a fast ejected beam. Discrepancies observed $< \pm 2\%$. Therefore, the relative calibrations indicate a very good performance of the SEC under constant conditions. No saturation was observed for up to $10^{18}$ cm$^{-2}$ sec$^{-1}$ proton flux densities.
d) SEC efficiency against incident proton momentum

Table 4 summarizes some relative measurements of the SEC efficiency against incident proton momentum, based only on slow ejected proton beams and the fluxes of the protons were determined by aluminium foil activation methods. However, we cannot give an absolute SEC efficiency against energy because the variations seem to be less than the overall error of the proton flux determination by the activation methods. For the same reason we cannot report long-term stabilities of SEC efficiency either.

We have programmed for the near future a more precise investigation of the SEC efficiency dependence against incident proton momentum. We believe that there is energy dependence on SEC efficiency. The SEC could then be used in the future generations of very high-energy phenomena as an identification detector of heavy particles.

SEC CALIBRATION

The most difficult problem encountered with the SEC up to now is its absolute calibration, i.e. to measure the SEC efficiency, which is defined as follows:

\[ \rho = \frac{\text{Number of emitted electrons}}{\text{Number of incident protons}} \times 100\% \]

Therefore two quantities must be measured carefully and independently. The charge of emitted electrons is measured directly from burst to burst by the gated electrometer for charge measurements with good accuracy. However, the big difficulty arises from the second quantity, i.e. the equivalent charge of the incident proton beam, which must also be determined with good accuracy and absolute criteria for intercalibration of the different monitoring systems of the same beam. These absolute criteria will permit us to compare the results with other laboratories. Most of the reported works with SEC's concern electron beams of energies within the MeV range. That is why they used "Faraday cups" as reference monitors and compared the SECs' outputs (see Table 2). This is not possible with proton beams of energies within the GeV range.
Table 4
Energy dependence of the SEC efficiency

<table>
<thead>
<tr>
<th>Proton momentum GeV/c</th>
<th>SEC efficiency $\rho$ in %</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Over-all</td>
<td>Per emitting surface</td>
</tr>
<tr>
<td>7</td>
<td>7.29</td>
<td>1.82</td>
</tr>
<tr>
<td>8</td>
<td>7.48</td>
<td>1.87</td>
</tr>
<tr>
<td>9</td>
<td>7.49</td>
<td>1.87</td>
</tr>
<tr>
<td>10</td>
<td>7.62</td>
<td>1.90</td>
</tr>
<tr>
<td>11</td>
<td>7.64</td>
<td>1.90</td>
</tr>
<tr>
<td>12</td>
<td>7.87</td>
<td>1.96</td>
</tr>
<tr>
<td>16.7</td>
<td>8.49</td>
<td>2.12</td>
</tr>
<tr>
<td>19.2</td>
<td>8.50</td>
<td>2.12</td>
</tr>
</tbody>
</table>

For all the above measurements, the proton flux was determined by activation methods, namely the reaction

$$^{27}\text{Al}(p,3\text{pn})^{24}\text{Na}$$

with $\sigma = (8.6 \pm 0.5) \times 10^{-27} \text{ cm}^2$.

Absolute errors are not taken into consideration for this relative energy dependence of the SEC efficiency. The statistical errors are $\sim 2\%$ for all measurements.

N.B. These relative SEC efficiencies against energy of incident proton are $\sim 20\%$ less than those efficiencies we repeatedly obtained with reference to current transformer reading during fast ejection.
However, "foil activation" is a well-established technique for measuring the absolute value of the flux of high-energy proton beams \(^{33, 34, 35, 36}\).

This technique may be defined as a chemical or isotopic analysis by means of inducing artificial radioactivity within a specimen through particle bombardment.

During an effectively continuous period of irradiation the activity arising from a direct product of a nuclear reaction will increase according to the equation

\[
A(t) = \sigma FN \left(1 - e^{-0.693 \frac{t}{T}}\right)
\]

in which

- \(t\) = continuous period of irradiation in time units
- \(A(t)\) = activity in disintegration per unit time at the end of irradiation
- \(T\) = half-life of radio-isotope formed in time units
- \(\sigma\) = activation cross-section for the reaction
- \(F\) = flux of activating particles
- \(N\) = total number, within the irradiated specimen, of atoms of the isotope from which the radio-isotope is formed.

In the case where the bombarded material is a thin foil and the activating particles traverse it perpendicularly:

\[
N = n \cdot S
\]

where
- \(n\) = number of atoms per \(cm^2\) of the foil irradiated
- \(S\) = irradiated surface of the foil in \(cm^2\).
The number of atoms per cm$^2$, $n$, can be calculated directly using the formula

$$n = \frac{\xi N_a}{M}$$

where $\xi$ = thickness of the foil in g cm$^{-2}$

$N_a$ = Avogadros number = $6.023 \times 10^{23}$

$M$ = molecular weight of the foil material

So

$$N = \frac{\xi N_a S}{M}$$

For irradiation times that are short compared to the half-life of the product the activity generated within the specimen is nearly proportional to the dose it has received.

$$A(t) \sim \sigma FN \quad \text{if} \quad t \ll T$$

We call now $A_o$ the induced activity just at the end of the irradiation time. Any later measurement of the irradiated foil activity, say $t$ times units after the end of irradiation, will be given by the formula

$$A_t = A_o e^{-0.693 t/T}$$

or

$$A_t = A_o e^{-\lambda t}$$

where $\lambda$ = the decay constant of the radio-isotope = $\frac{0.693}{T}$

Equation (1) permits the calculation of any one of the included factors (parameters) providing the rest of the factors are known or can be measured. So the flux, $F$, of the bombarding particles can be calculated if one can measure the activity $A_o$ and $\sigma$, $T$, $t$ and $N$ are
known. The activity $A_0$ of the irradiated foils is measured by three different counting methods, according to the properties of the chosen radio-isotope. These three counting methods are

1) gamma counting system ($\frac{dE}{dx}$ counters, semiconductor detectors, proportional counters)
2) beta counting systems (Geiger-Muller tubes, proportional counters)
3) beta, gamma coincidence counting system.

In Table 5 we summarized the nuclear reactions we have used up to now for measurements of the proton fluxes in the ejected beams of the CPS.

The reaction $^{27}\text{Al} (p, 3\text{pn})^{24}\text{Na}$ is the most used up to now. This is due to the very suitable properties of the radio-isotope $^{24}\text{Na}$. We notice, however, that the production of $^{24}\text{Na}$ from aluminium is particularly sensitive to secondary particles. For instance, the cross-section of the nuclear reaction

$$^{24}\text{Al} (n, \alpha)^{24}\text{Na}$$

is 120 mb. Hence one 14 MeV neutron is more than ten times as effective as a high-energy proton in producing $^{24}\text{Na}$ from aluminium.

Up to now the above reaction gave rather unsatisfactory results for the determination of the ejected beam fluxes 12) 36).

The accuracy of the cross-sections of the used reaction is of the order of $\pm 5\%$. To this absolute error of the proton flux determination a considerable percentage must be added for systematic errors due to unknown foil activation conditions and the measurement of the radio-isotope activity itself. Recently a CERN FORTRAN program "GA.PLOT" was written to eliminate a number of errors in calculating the activity from the spectrum of the gamma counting systems 37).
Table 5

Used nuclear reactions for proton flux measurements and the properties of corresponding isotopes

<table>
<thead>
<tr>
<th>Nuclear reaction</th>
<th>Cross-sections of the reaction $\sigma$ in mb for incident proton momenta</th>
<th>Adopted properties of the daughter nuclide</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reported Ref.</td>
<td>Adopted 7 - 28</td>
</tr>
<tr>
<td>------------------</td>
<td>----------------</td>
<td>----------------</td>
</tr>
<tr>
<td>$^6\text{Li}$($p$,pn)$^4\text{C}$</td>
<td>26.9 ± 5%</td>
<td>26.8 ± 5%</td>
</tr>
<tr>
<td>$^6\text{Li}$($p$,3p3n)$^7\text{Be}$</td>
<td>10.8</td>
<td>9.2</td>
</tr>
<tr>
<td>$^27\text{Al}$($p$,5p5n)$^{30}\text{F}$</td>
<td>6.3 ± 6.5%</td>
<td>6.2 ± 6.5%</td>
</tr>
<tr>
<td>$^27\text{Al}$($p$,3p3n)$^{24}\text{Na}$</td>
<td>8.6 ± 6.5%</td>
<td>8.6 ± 6.5%</td>
</tr>
<tr>
<td>$^{27}\text{Al}$($p$,3p3n)$^{22}\text{Na}$</td>
<td>11.6 ± 7%</td>
<td></td>
</tr>
</tbody>
</table>


In addition to the above-mentioned foil activation method the calibration of the SEC's was also based on:

1) the cross-section in proton - proton scattering experiments
2) the current transformer for the fast ejected proton beam.

In Table 6 a number of SEC calibrations are reviewed.

In this Table the diversity of the obtained efficiencies of the SEC 5 is very well demonstrated. With such big discrepancies, it is not sufficient to take simply the mean value of all measurements and give the SEC 5 efficiency. Fortunately, the stability of the SEC 5 during the p - p elastic scattering experiment was excellent, but the absolute error of the proton flux estimated by the monitoring method is ± 20%.

But as the SEC is also a linear detector for proton fluxes corresponding to those of fast ejected beams, where the induction type monitor works well, the SEC efficiency was based on this last monitor, which gave discrepancies of less than 2% over a long period of time. However, the absolute calibration of this induction type monitor is not very well known.

We therefore conclude empirically that the aluminium foil SEC has an efficiency per emitting foil

\[ \rho_e = (2.5 \pm 0.2)\% \]

with incident protons of 19.2 GeV/c momentum.

The results obtained with the SEC 20 or SEC 40 are very similar to those of SEC 5. Therefore, direct comparison of the SEC 5 and SEC 40 signal installed in the same beam gave corresponding electron collection ratios of the same order as the ratio of their corresponding number of emitting surfaces.

Our future programme is to study further the influencing factors on the SEC efficiency, using the induction type monitor as a reference and at the same time to study the activation foil methods.
Table 6

Selected SEC 5 efficiency measurements in the $e_2$ ejected beam

<table>
<thead>
<tr>
<th>Run</th>
<th>Circulating proton/burst $\times 10^{11}$</th>
<th>Mean of bursts</th>
<th>Proton momentum GeV/c</th>
<th>Ejected proton/burst $\times 10^{11}$</th>
<th>Monitor</th>
<th>Efflo. of ejection</th>
<th>SEC 5 emitted electrons/burst $\times 10^{10}$</th>
<th>SEC 5 efficiency %</th>
<th>Remarks</th>
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<tr>
<td>1</td>
<td>5.45</td>
<td>17</td>
<td>19.2</td>
<td>4.07</td>
<td>$^{14}$Na ($\beta$)</td>
<td>75</td>
<td>3.36</td>
<td>8.2</td>
<td>2.05</td>
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<tr>
<td>2</td>
<td>5.75</td>
<td>&gt; 100</td>
<td>19.2</td>
<td>3.45</td>
<td>$^{14}$Na ($\beta$)</td>
<td>60</td>
<td>2.92</td>
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<tr>
<td>3</td>
<td>8.32</td>
<td>1240</td>
<td>19.2</td>
<td>3.52</td>
<td>$^{14}$C ($\beta$)</td>
<td>44</td>
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<td>11.8</td>
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<td>4</td>
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<td>16.7</td>
<td>5.75</td>
<td>$^{14}$F ($\beta$)</td>
<td>58.5</td>
<td>3.96</td>
<td>6.9</td>
<td>1.72</td>
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<td></td>
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<td>idem</td>
<td>idem</td>
<td>$^{14}$Na ($\gamma$)</td>
<td>65</td>
<td>idem</td>
<td>6.2</td>
<td>1.52</td>
</tr>
<tr>
<td></td>
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<td>idem</td>
<td>idem</td>
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<td>7.0</td>
<td>1.82</td>
</tr>
<tr>
<td></td>
<td>idem</td>
<td>idem</td>
<td>idem</td>
<td>1.21</td>
<td>$^{14}$Na ($\gamma$)</td>
<td>13.2</td>
<td>idem</td>
<td>7.0</td>
<td>1.82</td>
</tr>
<tr>
<td>6</td>
<td>8.71</td>
<td>1000</td>
<td>19.2</td>
<td>6.12</td>
<td>2 $\mu$s electron transformer</td>
<td>6.02</td>
<td>10</td>
<td>2.5</td>
<td>1.92</td>
</tr>
<tr>
<td>7</td>
<td>8.65</td>
<td>1000</td>
<td>19.2</td>
<td>2.74</td>
<td>$^{14}$O ($\gamma$)</td>
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<td>2.62</td>
<td>9.56</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
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<td>idem</td>
<td>idem</td>
<td>3.02</td>
<td>$^{14}$C ($\beta$)</td>
<td>35</td>
<td>idem</td>
<td>8.67</td>
<td>2.17</td>
</tr>
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<td>idem</td>
<td>idem</td>
<td>2.27</td>
<td>$^{14}$F ($\beta$)</td>
<td>26.3</td>
<td>idem</td>
<td>11.5</td>
<td>2.87</td>
</tr>
<tr>
<td></td>
<td>idem</td>
<td>idem</td>
<td>idem</td>
<td>2.42</td>
<td>$^{14}$Na ($\beta$)</td>
<td>28.1</td>
<td>idem</td>
<td>10.8</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>idem</td>
<td>idem</td>
<td>idem</td>
<td>2.42</td>
<td>$^{14}$Na ($\gamma$)</td>
<td>28.1</td>
<td>idem</td>
<td>10.8</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Remarks:
- 120% (see also Fig. 21)
- Simultaneous activation of all foils and measurements
- Slow ejection. Not optimized for efficiency
- Fast ejection (see also Fig. 22)
- 10% $\gamma$ emission
- Nuclear Physics Group
- Health Physics Group
for determining which one of the commonly used nuclear reactions is the most suitable under the CPS ejected proton beam conditions.

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GENERAL LAYOUT OF THE CPS, SHOWING THE EXPERIMENTAL HALLS, THE ACTUAL EJECTION SYSTEMS AND THE CORRESPONDING EJECTED PROTON BEAMS.

Fig. 1
Fig. 2  TIME STRUCTURE OF THE FAST EJECTED PROTON BEAM

OSCILLOGRAM OF A SCINTILLATION COUNTER SIGNAL
SENSITIVITY: 2 V/cm
SWEEP: 2 μsec/cm
INPUT: 75 Ω

Fig. 3  TIME STRUCTURE OF THE SLOW EJECTED PROTON BEAM

UPPER TRACE
SEC SIGNAL
SENSITIVITY: 50 mV/cm
SWEEP: 50 msec/cm
SEC BIAS +400 volts
EJECTED PROTONS AFTER REF. 3, 10

LOWER TRACE
ELECTROMETER GATE SIGNAL
5 V/cm
SWEEP: 50 msec/cm
PRINCIPLES OF SECONDARY EMISSION CHAMBER

FIG. 4
SCHEMATIC DRAWING OF THE SECONDARY EMISSION CHAMBER (SEC 5)

Fig. 5
Fig. 6  DETAILS OF THE WINDOW AND FOIL ASSEMBLY OF THE SEC 20
FIG. 7

The three parts of the roll frame.
Fig. 8 SEC 40 SCHEMATIC DRAWING
Fig. 9  PHOTO OF THE HALF SEC 20 AND THE FOIL ASSEMBLY
Fig. 10 PHOTO OF THE FOIL ASSEMBLY
Fig. 11  PHOTO OF SEC 40 IN THE e3 EJECTED PROTON BEAM
SECONDARY EMISSION CHAMBER

H.T. POWER SUPPLY

VAC-SORS ROUGHING PUMP

THE S.E.C. AND ITS VACUUM SYSTEM

Fig. 12
Fig. 13 PHOTO OF THE SECONDARY EMISSION CHAMBER AND ITS VACUUM SYSTEM
BLOCK DIAGRAM OF SECONDARY EMISSION CHAMBER OPERATION AND INTERCONNECTIONS

SEC LOCATION

CHARGE MEASURING DEVICE LOCATION

SEC BIAS P S + 500V

SOLID STATE DIFFERENTIAL OPERATIONAL AMPLIFIER CONNECTED AS ELECTROMETER

DIGITAL VOLT-METER

LOCAL CONTROL

DIGITIZER

PULSE (FORMER) GENERATOR

TO USERS

VACION PUMP

0.1 - 5 µA ~10^-8 torr

VACION PUMP CONTROL UNIT

50nF

75Ω

STORAGE CAPACITOR

SP2A PHILBRICK

GAIN = n+1

n = 0, 1, 4, 9

10^11 Ω (DYNAMIC)

RL1 = DRY REED RELAYS

GATE SIGNAL at B 610 mA

GATE SIGNAL at B 100 mA

ELECTROMETER OUTPUT at C 0.10 V

PULSE GENERATOR OUTPUT at D 100 kc 10 V 40 µs

ELECTROMETER RESET at E 6 V 100 mA

Fig. 14
FIG. 15 General layout of the 58 ejection system and the $e_2$ ejected proton beam
FIG. 16 SEC 5 position in $e_2$ ejected proton beam, and the Layout of proton-proton elastic scattering experiment.
Fig. 17

SEC 5 EFFICIENCY ≈ 12%
(ACCORDING TO REF. 27)

EACH POINT IS THE MEAN VALUE OVER 10 SUCCESSIVE BURST READINGS
Fig. 18. ENERGY DISTRIBUTION OF SECONDARY ELECTRONS EMITTED BY ALUMINIUM FOILS
THESE CURVES AND THE SEC 5 USEFUL FOIL SURFACE DIMENSIONS DETERMINE THE PROTON BEAM SPOT CROSS SECTION DIMENSIONS.

SEC EFFICIENCY AGAINST INCIDENT PROTON SPOT POSITION ON SEC FOILS.

Fig. 19
Fig. 20  CONTACT PRINT OF AN IRRADIATED ALUMINIUM FOIL SHOWING THE PROFILE DIMENSIONS OF THE EJECTED PROTON BEAM DURING THE SEC 5 PERFORMANCE TESTS.
Fig. 21
SEC 5 LINEARITY FOR SLOW EJECTED PROTONS
(Proton momentum 19.2 GeV/c)

SEC. EFFICIENCY = 12 %

○ MEAN VALUE OVER 10 SUCCESIVE BURSTS: IP INCREASING
○ MEAN VALUE OVER 10 SUCCESIVE BURSTS: IP DECREASING

(BASED ON FP-ELASTIC SCATTERING CROSS-SECTION MEASUREMENTS REF. 27)
Fig. 22 SEC 5 LINEARITY FOR FAST EJECTED PROTONS

(Proton momentum 16.7 GeV/c)