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BEAM INSTRUMENTATION FOR AN ISOL TEST STAND

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TRIUMF is constructing a test bed for the first stages of the proposed TISAC accelerated radioactive beam facility. We will present the requirements for the diagnostic system for this test stand and describe the design and development work underway. Scintillators, beamstops and a Faraday Cup have been tested using stable, mass analyzed, 12 keV beams of ions from mass 14 to 132. The design of a linear drive, with 10 µm resolution, for scanning wires and slits has begun.

1 Introduction

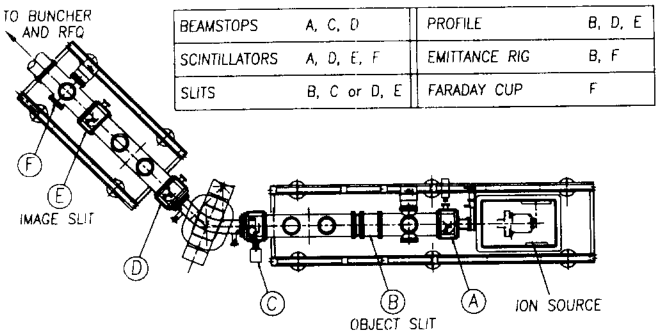
TRIUMF has operated an ISOL (Isotope Separator On Line) for 7 years[1]. Up to 1 µA of protons, usually at 500 MeV hit a thick target. Spallation products diffuse out of the hot target and are ionized in either an ECR or surface ion source. The source is biased at 10 to 20 kV and the, usually, singly charged ions are transported through a mass analysis system with electrostatic focusing; the mass resolution (m/Δm) is 1000.

The laboratory has been funded recently to build a new facility[2] designed to accommodate proton beams of 10 µA. The source bias voltage may be as high as 60 kV and the resolution of the mass analysis system (m/Δm) should equal or exceed 8000. The analyzed beam may be directed to a low energy experimental area or matched into an RFQ for acceleration to higher energy. Experiments at low energy may use ions with mass up to 84 or higher and the source may be operated near maximum voltage. When matched to an RFQ all ions must have the same velocity and the source voltage will be adjusted to give 2 keV/amu.

One of the first steps in this programme will be to build a test station which will mimic the ion source and first stage of acceleration. It will be used to develop ion sources, diagnostic and other equipment and to check the ion optics using ions of stable isotopes; there will be no radioactivity. This paper discusses some of the beam diagnostic instrumentation requested to commission and develop the test station, not the instrumentation for the final radioactive facility. (Ref. 3 describes instrumentation for reliable operation in a radioactive environment).

2 A Description of the Test Station and Diagnostic Requirements

Until very recently it was planned to construct a test station with two modes of operation[4]; a high acceptance low resolution mode and a low acceptance high resolution (m/Δm=8000) mode. The latter required focal plane and object slit widths of ±0.2 mm when matched to existing sources with emittance ±5 mm × ±0.5 mrad. Ion source improvements are anticipated and adjustable slits capable of operation down to ±0.1 mm and with a precision of about 10%, i.e. 10 µm, were requested. In August it was decided to take advantage of an existing magnet and to construct quickly a high acceptance test station with a resolution of 300. This will relax requirements on precision in the short term but high resolution equipment will still be required in the long term.



BEAMSTOPS	A, C, D	PROFILE	B, D, E
SCINTILLATORS	A, D, E, F	EMITTANCE RIG	B, F
SLITS	B, C or D, E	FARADAY CUP	F

Fig. 1. The test station under construction.

The revised test station is illustrated in Fig. 1. A four quadrupole matching section transfers the beam from the ion source to the object slits in box B. Electrostatic quadrupole triplets before and after the dipole provide unit magnification in both planes and produce a momentum dispersed image in the focal plane in box E. The diagnostic equipment required is summarized in Fig. 1. It includes items such as beamstops, low resolution profile monitors and an emittance measuring system[5] that have been used at TRIUMF for a number of years. It also includes items unfamiliar to us but which may be in common use elsewhere.

These items include:

- Scintillators for low, 10-60 keV, heavy ion beams. These are useful during commissioning and can give information not easily obtained by other means[6].

- High precision, 10 µm, linear drives for adjustable slits and scanning profile monitors at the object and focal plane locations of the future high resolution mass separator.
- Faraday Cups for accurate current measurement and for detecting fast, up to 4 MHz, fluctuations in the current of the slit selected beams.

The energy/range regime, Fig. 2, is also unfamiliar.

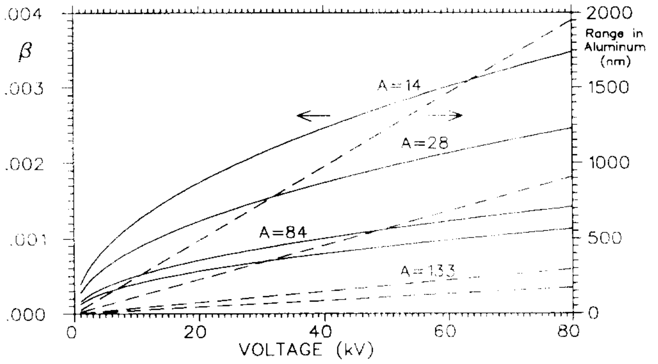


Fig. 2. β and range in aluminum of singly charged ions as a function of energy (range data Ref. 7).

The production of the relatively sparse radioactive beams, say 10 pA to 0.1 µA, is accompanied by intense beams of unwanted species, up to tens of microamps in the presently operating TRIUMF ISOL. They may be abundant, more stable, isotopes of the desired beam, carrier gas, molecular ions, etc. They will have a similar emittance to the desired beam and the charge and mass may be similar. The electrostatic optics will produce similar spot sizes and they may not be clearly separated from the desired beam until late in the separator. It is anticipated that new sources may produce up to 10 mA, i.e. 600 watts, of unwanted beam, and the power density on the object slit and equipment nearby could be 60 watts/mm^2 necessitating cooling.

The status of the design and development of these items is given below. We have been able to do some tests on the existing ISOL facility, which is equipped with gas leaks to provide mass analyzed stable beams. We also have access to a laboratory test stand originally built to develop H$^-$ sources but being modified for heavy ion source development.

3 Scintillators

Zinc Sulfide screens, 996 Alumina substrate and Chromox Type 6 [8] have been tested on ISOL and the laboratory test stand. ZnS has high light output at between 400 and 500 nm. Chromox-6 (chromium doped alumina) is a ceramic which is suitable for placing in clean environments. It emits a narrow band at 690 nm and can operate at higher temperatures.

These screens have already yielded useful information during our brief testing programme. They have confirmed annular N$^+$ beams from a cusp source, suggested the existence of second order aberrations following a switching magnet and shown several instances of double beam spots. Previous attempts to use scintillators in ISOL had been abandoned because of the difficulty in distinguishing between real changes in beam shape and discharges caused by the accumulation of charge on an insulating surface. This remains a problem. The current at which sparking begins is about five times that at which light is just discernible. The surface could be discharged by a metal coating thick enough to provide a resistance of <1 MΩ per square but thin enough to allow ions to penetrate and light to escape (unless a transparent medium is viewed from the rear). The self absorption distances (60 µm for ZnS and almost 1 mm for Chromox-6) are greater than the ranges[7] of 12 keV ions, of order 100 nm, which in turn are greater than the absorption distance for light in titanium, nickel or gold, about 20 nm. Optical transmission then determines the coating thickness for opaque scintillators. It should be noted that these thin layers may not be homogeneous or even be physically continuous and extrapolation of bulk properties may be unreliable.

An electron beam evaporator at the TRIUMF microelectronics fabrication facility was used to coat a Chromox-6 sample with 20 nm titanium. When exposed to a 17 keV beam of N$^+$, with a <1% admixture of H$^+$, the coated portion was judged to give half the light output of the uncoated portion and a less crisp image. Most of the light came from hydrogen, which has a much greater range. Unfortunately the evaporated coating did not provide electrical continuity. The grain size of Chromox-6 is said to be 3 µm and the surface roughness measured on different samples ranged from 0.13 to 1.3 µm. We were advised that polishing may not smooth the surface sufficiently for a continuous evaporated layer and that sputtering would be more effective. Gold-palladium layers, nominally 10 and 20 nm, were sputtered onto 996 alumina and Chromox-6. Electrical continuity was achieved but no light came through the coated portion. We have had less control over the sputtering process and the coatings may be thicker than intended.

The response of uncoated samples was measured. Ion beams of mass 14, 16, 20, 40, 84 and 132 with 12 keV energy were run onto freshly deposited ZnS screens. The brightness/current density seemed to decrease roughly as $1/Z_{ion}$, where Z is the atomic number. This would be in agreement with the expected range which is dominated by nuclear stopping power at these energies and which is shorter than the self absorption distance. The discharge, or flash over, rate increased with current density with a threshold value which increased with mass from ≈ 3 nA/mm^2 for N$^+$ to ≈ 60 nA/mm^2 for Xe$^+$. Some diminution of light output was seen after several hours of operation but inspection showed that this was due to a coating of the surface near the beam spot. The effective lifetime will be determined more by the cleanliness of our system than by physical effects in the scintillator.

Fig. 3 shows contour plots of beam spots digitized using an Imaging Technology FG100-Q Q bus card installed in a MicroVAX 3100 computer. The fingers at the lowest contour level, Fig. 3a, did not correlate with tuning changes and are considered a type of discharge. The system was also used to videotape spark overs.

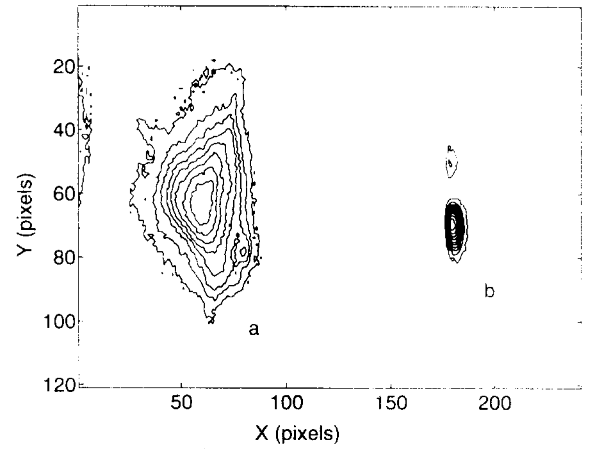


Fig. 3. a) 280 nA N^+ on 996 Alumina, b) 100 nA on Chromox-6.

4 Precision Scanning Wire Profile Monitors and Slits

TRIUMF has several different slit, scanning wire and scanning blade designs but none with a precision of 10 µm (0.4 mil); however this precision has been approached elsewhere[9]. A linear drive was thought more precise than a rotary mechanism for a profile monitor and will be needed for the slits. A modular approach was adopted for the preliminary design of both so that units could be identical and stacked together. The diameter of the profile monitor wires must be compatible with the desired resolution; an easily handled 32 µm carbon monofilament would be used initially, changing to 7 µm monofilament when required. The signal current is expected to range from 0.1 nA to 10 µA; it would be amplified by a TRIUMF QSX amplifier[10] with a bandwidth of 100 Hz. Direct acquisition by a computer could be slow and TRIUMF's existing scanners use KineticSystems 4022/4050 transient recorders which digitize 8 analogue channels at a 31 kHz rate for up to 10^4 values in each channel. The amplifier bandwidth and mechanical settling time may extend the sampling time to 10 ms in which case 10^4 data points would require 100 seconds. The transient recorder has a "present value" output which allows data to be displayed during accumulation; nevertheless 100 s would be a long time for many scans and the options of scanning faster with coarser steps and high resolution scans over a reduced range should be available. Short scans in one plane may also use a stationary wire and steering magnet technique.

Most of the time the slit jaws will be driven to a destination and beam measurements not commence until the position and gap width are set. Occasionally, e.g. for very weak beams, or if the linearity of the optics during a magnet scan is suspect, it may be desirable to scan the slit with a fixed aperture while measuring the transmitted beam current. A hardware pulse per step signal from the master motor controller card to the slave motor controller card would allow synchronization of movement. If the resulting jitter of one or two steps is not acceptable then both jaw motors could be driven from a single Compumotor card, but at more expense.

Each slit jaw or scanning wire carriage would be mounted on a common ball slide and driven by a ball screw and micro-stepper motor, mounted on the outside of the diagnostic box, through a link and bellows unit that also allows for the transport of the cooling water to the slit jaw. The micro-stepper motors would be controlled by an open loop system and the prototype would also be monitored by an incremental optical linear encoder.

5 Beamstops and Faraday Cups

The ISOL operating at TRIUMF uses a Keithley electrometer to measure the beam current hitting simple unbiased beamstops. The incident ions may produce secondary electrons and sputter target material as both atoms and ions. The beam stops may also register stray charges from the surroundings. Fig. 4 shows the current measured from a biased stainless steel plate exposed to a 12 keV N^+ beam at normal incidence. The current was measured by a Keithley 485 Electrometer floating at the bias potential. Small changes in bias potential about zero volts have a dramatic effect on the current measured. Similar results were obtained for an aluminum target and with argon and krypton beams. They are affected only slightly by changes in local vacuum.

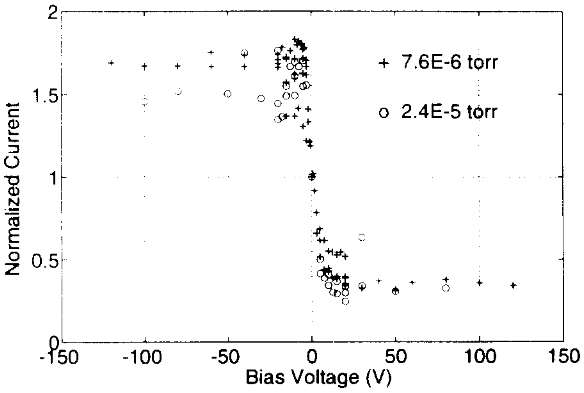


Fig. 4. Current from a biased stainless steel plate, 12 keV N^+ incident beam.

A series of measurements were made with a stainless steel Faraday Cup of the CERN-ISOLDE wide aperture type illustrated in Fig. 5. The results shown in Fig. 6 were obtained with the cup near ground and the suppressor ring biased; the conventional mode of operation[11]. We also made measurements with cup and suppressor connected and with cup biased and suppressor near ground. We concluded that secondary electron currents are similar in magnitude to the beam current; that backscattered beam and sputtered ions contribute <3% and that charges from the environment are ≤10%. While the Faraday Cup with conventional bias is clearly superior, the unbiased plates, which tend to read high, can still be a useful means to check and tune beams.

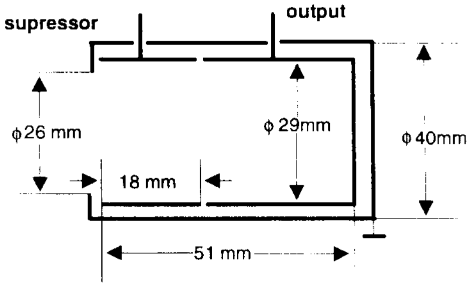


Fig. 5. CERN-ISOLDE style wide aperture Faraday Cup (courtesy E. Kugler).

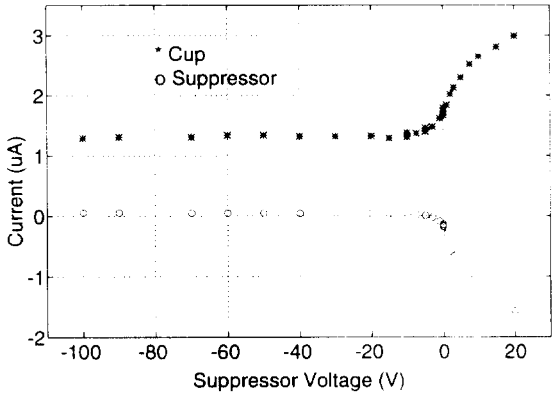


Fig. 6. Cup and biased suppressor currents, N^+ ions.

It may be that the current of a selected species may fluctuate due to sparking electrodes, power supply ripple, plasma oscillations, etc. It is planned to provide an additional Faraday Cup with 50Ω impedance and a bandwidth much greater than the 4 MHz requested.

It is assumed that the beam spot through the slit will be small and a collector diameter of 25 mm will suffice. The cup would then be the usual tapered cone with outer and inner radii in the ratio of 2.30. Such a device would become quite long should it be necessary to scale it up to collect all the beam in the 100 mm pipe. It is possible to foreshorten a cup by using a double conical structure and still avoid reflections. The characteristic impedance of a bi-conical line can be calculated with the following expression[12]:

$$Z_0 = \frac{1}{2\pi}\sqrt{\frac{\mu}{\varepsilon}}\ \ln\frac{\tan(\arctan((D_2 - D_1)/2L)/2)}{\tan(\arctan((d_2 - d_1)/2L)/2)}$$

where, D_2, d_2, and D_1, d_1 are the inner and outer diameters of the concentric conductors at the ends of the bi-conical line, and L is its length, Fig. 7. A 50Ω bi-conical line can be made with any desired length by adjusting D_2, d_2, D_1 and d_1.

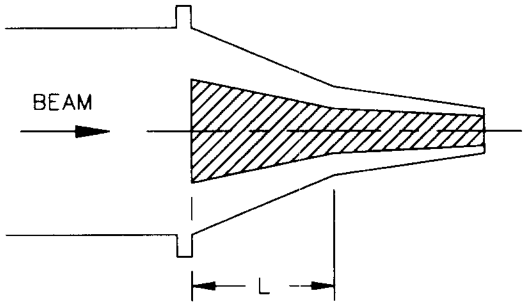


Fig. 7. A bi-conical collector for a Fast Faraday Cup.

6 Conclusion

The experiments described above have given us confidence in preparing equipment for the test stand. We will continue to try to extend the useful dynamic range of scintillators; the higher energy and clean, stable environment of the test stand should help. The design of the precision linear drive will be completed and, hopefully, a prototype constructed.

Acknowledgments

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