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THE INSTALLATION OF A PROTOTYPE ON-LINE ISOTOPE SEPARATOR AT TRIUMF (TISOL)

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Abstract

A test ISOL (TISOL) has been designed and constructed mainly for the ion source development work necessary for the proposed TRIUMF-ISOL Facility. The ion beam transport and isotope separator system consists of two quadrupoles and a 90° vertical bend dipole (QQD). One special feature of TISOL is that the relative position of the quadrupole doublet may be adjusted so as to accommodate a large variety of target-ion sources (TIS). These will include surface ionization, plasma, on-line ECR and laser-based ion sources. The performance of the QQD for various TIS systems will be discussed. The calculated resolution (based on second-order TRANSPORT) for an emittance of 25π mm-mr in the bend plane and 120π mm-mr in the non-bend plane is about one in 1000. The facility is presently under development and the optimal optical configuration has not yet been achieved.

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1. Introduction

In June 1985, a collaboration of scientists from various institutions including McGill University, Simon Fraser University, Queen's University, The University of Toronto, TRIUMF and Chalk River Nuclear Laboratories submitted a proposal to TRIUMF to build a state-of-the-art on-line isotope separator (ISOL) at TRIUMF, called the TRIUMF-ISOL Facility[1,2]. The value of such a facility at TRIUMF has been dealt with at length in the proposal and in the proceedings of two workshops: one held in June 1984 on the ISOL[3] and one held in September 1985 on the acceleration of the separated ion beam[4].

As part of this project, it was decided that the building of a test facility (TISOL) would be a worthwhile pursuit.

The primary purpose of TISOL is the development and testing of new target-ion source (TIS) systems for use on the proposed ISOL Facility[1,2]. These new TIS systems will be designed to satisfy the requirements of the scientific research to be done with the TRIUMF-ISOL, as well as the configuration of the separator system itself (particularly the vertical bend plane).

A second reason for the building of TISOL is the development of the technical experience at TRIUMF with on-line isotope separators and the testing of various engineering design questions relevant to the proposed high intensity TRIUMF-ISOL. Such questions include new methods of remote

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operation and handling of highly radioactive (yet fragile) TIS systems, the possible effects of high proton beam intensities on thick targets, and new approaches to obtaining a vacuum in a high radiation field. The concept of a vertical bend plane ISOL is, in itself, quite novel and requires much study.

Finally, subordinate to the above purposes, the TISOL may be used for selected physics research projects so as to strengthen the expertise of the TRIUMF-ISOL group.

2. General Design Specifications

As a test facility, it is clearly important that the TISOL mimic some of the basic features of the proposed TRIUMF-ISOL Facility. The most important of these features is the QOD configuration with the bend in the vertical plane to bring the extracted radioactive beams above the thick shielding. Thus, silt extraction orifice ion sources must be redesigned with horizontal slits.

Another important feature of the two facilities are their ability to accommodate a wide variety of ion sources. This may be accomplished with the two quadrupoles, whose positions and fields may be changed to maximize the acceptance of the QOD. The overall acceptance of the QOD, and its optical versatility, are also enhanced by the large dipole we have obtained (along with the quadrupoles) from the University of Colorado. In order to

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maximize these effects, the dipole gap was widened to δ cm, leaving an effective bend-plane aperture of 20 cm. The large dipole aperture allows us to focus the beam with a large dispersion-to-magnification ratio, which yields a high resolution. By focusing the beam a large distance from the dipole, the collection chamber may be effectively shielded against the gamma and neutron radiation from the target itself.

Finally, in order to effectively test TIS system properties, as well as other aspects of the facility, a sophisticated monitor and control system is needed. This information is necessary for the ultimate design of the proposed TRIUMF-ISOL Facility.

3. Layout of the Separator Facility

A plan view of the TISOL in its future position on-line is shown in fig. 1. The target-ion source chamber is to be mounted on beam line 4A at the TRIUMF cyclotron. The TIS system extracts and ionizes isotopes produced in the target matrix, preferably with chemical (Z) selectivity. The variable primary proton beam energy (200-520 MeV) allows a wide variety of nuclear reactions. Details on the TIS may be found in Section 5.

An elevation view of the TISOL on-line is shown in fig. 2. The ion source is at HT and the ions are accelerated towards a grounded electrode. The potential difference is presently a maximum of 20 kV but may be increased to the 60 kV envisioned for the TRIUMF-ISOL. The ion beam passes

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through the QQD and is bent 90° vertically. The beam is focused at a point 2.7 m above the exit of the dipole, allowing it to pass through a hole in a 1.2 m thick high-density concrete shielding block. The shielding between the 2.4 m and 3.6 m levels has a gap above the magnet (which reaches a height of 2.7 m) to allow it and a turbopump to be positioned. The beam is focused in a collection chamber at the 5.5 m level. Eventually, a secondary beam transport system (STS) will be installed which takes the beam from the collection chamber, bends it horizontal, and transports it to one or more stations above the blocks at the 6.1 m level. A platform has been installed at the 9.1 m level on which the Faraday cage and control room are located.

4. Details of the Separator System

4.1 The Magnetic Separator (QQD)

The separator system is shown in fig. 3 on top of the blocks at the 6.1 m level, which is its position for off-line testing. The two quadrupoles (part of a four-quad zoom lens) and the dipole were built by the University of Colorado Nuclear Physics Laboratory as part of their energy-loss spectrograph[5].

The dipole is a 90° H-frame magnet and weighs 8000 kg. It was originally a split-pole device with a pole tip gap of 4.45 cm and width of 40.64 cm. The mean radius of curvature of the pole is 1.38 m. The large aperture means the dipole is capable of high resolution. However, the small

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gap and the focusing angles on the four pole edges yielded optics inappropriate to the present application. Thus, the dipole was modified by replacing the poles and widening the gap to 10 cm by introducing yoke shims. The two pairs of poles of the split-pole configuration were replaced by one pair, making it a conventional single pole device. The pole edge angles and curvatures, as well as the optical radius of curvature, were chosen so that the new poles fit in the yoke and produce beam optics appropriate to our application. The physical central curvature of the new poles is 1.38 m so that they fit within the excitation coils. However, the optical central trajectory has a mean radius of curvature of 1.25 m so as to provide space within the yoke for the entry angle on the pole, which is 30° . The exit angle is 22.3° . The entry pole edge curvature is 1.21 m and the exit curvature is 0.87 m, chosen to minimize geometric aberration for the horizontal slit source (see next section).

The two quadrupoles are equipped with three field clamps (they share one) and true hyperbolic poles. Because of the optical demands on these quadrupoles (by the original owners), they were designed to have low harmonic content, even up to 1.25 times their nominal aperture. As a result, these magnets are eminently suited to our application. The quad pair is mounted on a support system which allows their position along the beam axis to be changed by 23.7 cm. This feature was incorporated into the TISOL design to allow the use of ion sources of different sizes. For example, the TIS box for use with the surface and plasma sources (see Section 5.2) is small, which means that the distance between the proton beam line and the IS object is small. Thus, the quad pair should be placed

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upstream to maximize the acceptance of the system. For the ECR ion source (see Section 5.2), however, this distance is large and the quads must be moved downstream.

All three magnets were designed to sustain substantially greater fields than will be encountered in their present application and no saturation effects are anticipated.

4.2 Optical Design

Presented below are some of the physical and optical constraints on the design of the QOD:

- i) Horizontal length: Because of the constraints of floor space in the vault, the TISOL must sit in a space of about 3.9 m in length. In this space must sit the dipole itself, a monitor box, the two quadrupoles (which are quite long) and an initial drift space for the IS and extraction electrode. In addition, space must be reserved for gate valves. These constraints prove to be quite severe.
- ii) Vertical length: The QOD focus must be at a point between 5.3 and 5.6 m above the vault floor.
- iii) Dipole gap: For good efficiency, the beam should fill the gap and be close to parallel.
- iv) Quad apertures: Because the quadrupoles are long (43 cm effective length each), the beam divergence properties cause the beam size to change quite a bit over the lengths of the quads. This puts a constraint on the effective use of the quad apertures.

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- v) Target-Ion Source size: Since the distance from the proton beam line to the IS object may be very different for different ion sources, the quads are moveable over a length of 23.7 cm. Although this provides some optical flexibility, the distance from the proton beam line to the dipole is fixed.

- vi) Aberration: The first-order optical design should yield reasonably good second-order properties when sextupole corrections are added to the dipole.

Despite these constraints, an appropriate design was achieved. The drawbacks of this design are the size of the beam in the non-bend plane at the bend plane focus (for slit sources) and chromatic aberration (which produces a steep focal plane tilt of about 10°). However, the casualties appear to pose no threat to successful operation.

The optics have been studied for three ion source configurations: the surface/plasma, the ECR and the ISOLDE front end (see Section 5.2). The surface/plasma TIS configuration is small with the IS optical object only 4 cm from the target and has a long extraction slit to maximize transmission. This extraction geometry produces additional significant aberration and optical constraint on the separator system. In addition, the plasma source will be used to produce a wide range of masses whereas the ECR source will be used primarily for light ions, where resolution is not as important. Thus, the dipole optics (pole edge angles and curvatures) were chosen to optimize the performance for the surface/plasma TIS configuration.

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The TIS object is a horizontal slit 1 mm x 20 mm, which represents our "largest object" ion source. The bend plane divergence is 100 mr (limited by the acceptance of Q2) yielding a bend plane acceptance of 25π mm-mr, and 24 mr in the non-bend plane (limited by the dipole gap) yielding an acceptance of 120π mm-mrad. The first- and second-order optics for this configuration were calculated with the matrix optics program TRANSPORT[6]. To first-order, the quadrupole fields, dipole pole edge angles and drift spaces were allowed to float subject to the constraints already described, as well as a point-to-point focus in x and a beam waist in y. The last constraint was relaxed somewhat in order to satisfy the more critical constraints and maximize the acceptance. To second-order, the dipole pole edge curvatures were adjusted to minimize aberration for a slit source. These corrections also allow for the addition of a small sextupole before the focus which modifies the optics so as to minimize aberration for a point source.

The dispersion at the focus is 5.34 cm/% momentum or 2.67 cm/% mass. The bend plane magnification is 2, while the non-bend plane is magnified by 2.3. To first-order, the width of the image is given by $x = 1.1$ mm, which includes a generous allowance for the beam energy spread. This yields a resolving power of $M/\Delta M = 1200$. The second-order calculation attempts to minimize simultaneously the four geometric aberration terms associated with the beam divergence and slit length. Suitable minimization was only achieved when the first-order design was modified to allow the y-waist to move upstream of the x-focus. The image half-width that results is

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$x = 1.2$ mm, which is only 10% larger than the first order width, yielding a resolving power for this source of $M/\Delta M = 1100$.

Beam losses were deduced using the "local" second-order matrix ray-tracing code REVMOC[7]. A broad gaussian distribution of rays within the beam parameters previously described was assumed. The results indicate that about 8% of the beam is lost and that about 95% of the remaining beam falls within the width described by TRANSPORT.

The optics for the ECR source have also been calculated using TRANSPORT. In order to provide space for the ion source, the quad pair is moved 23.7 cm downstream. The quadrupole fields were adjusted to produce a double focus at the collection box. Since the IS object is close to the dipole, less of the dipole aperture is used, which lowers the resolution. The ECR object is a 1 mm diameter orifice. The width of the image is $x = 1.8$ cm to first-order and $x = 3.3$ mm to second-order. Beam losses were again deduced with REVMOC. The losses amount to 4% and about 96% of the remaining beam falls within the TRANSPORT width, yielding a resolving power of about $M/\Delta M = 400$. This resolving power is more than good enough for the low mass species to be studied with this ion source.

The optics for the ISOLDE front end have been calculated with the quads in the downstream position. For a 1 mm diameter object, the width is 0.9 mm to first-order and 2.6 mm to second order, yielding a resolving power of about $M/\Delta M = 500$.

It should be noted that these calculations do not accurately account for the fringe fields for the dipole. Since the poles are recessed from the yoke entrance and exit, there are significant low-field regions before and after the poles. Since this effect is hard to calculate (and costly), it was decided to machine each pole in three pieces: a main section and two edges. Then the dipole may be field-mapped and its true optics calculated. The results of this ray-tracing calculation will then indicate appropriate corrections to the dipole edge angles and curvatures, and new edge pieces may be designed and machined. The results of the ray-tracing calculation for the first set of pole edges are given in Section 8 and show that the dipole is significantly different from the TRANSPORT model.

4.3 Secondary Transport System (STS)

At present, the beam transport system comprises the QOD and takes the beam to the first focus above the shielding blocks. In the near future, a secondary transport system (see fig. 4) will be designed which takes the beam, bends it horizontal (90°) and refocuses it at one or more experimental stations above the blocks. After mass selection, the high quality optics of the QOD are no longer necessary. Although not designed in detail, we envision a system made up of a cylindrical bend, several electrostatic lenses, and possibly a switchyard.

4.4 Vacuum System

In order to minimize the scattering of ions by gas molecules, a vacuum of at least 10^{-6} torr must be achieved, especially in the region near the dipole exit. The vacuum system is fully interlocked by the control system to prevent vacuum accidents. The vacuum system is divided into three sections: the ion source section, the QOD section and the collection chamber above the blocks. For the surface/plasma TIS chamber, a high-speed cryopump (CTI-10) is used while for the ECR source, two 450 λ/s turbopumps are used. During operation, a vacuum no better than 5×10^{-5} torr will probably be achieved in this section. The QOD will be pumped by two 450 λ/s turbos, one before and one after the dipole. The volume which must be pumped is quite large, comprising about 2 m of beam line between the IS and the dipole, the dipole chamber itself (about 30 cm x 10 cm x 2 m) and the beam line from the dipole to the collection box (another 2 m).

The collection chamber itself will be pumped with a third turbopump. Although the relative number of ions of the wrong momentum is much reduced by this point, the solid angle of acceptance of these ions (after scattering) is much higher. Further, the long beam pipe between the dipole and the collection chamber (2.9 m) causes a large resistance to gas flow, necessitating a third system. Three roughing pumps will be employed to rough out the system and back the turbopumps.

At a later date, the STS will be installed. This system clearly needs good vacuum to support the HT of the electrostatic devices. The details

have not yet been decided but the control system is being designed to handle the additional requirements.

5. Targets and Ion Sources

5.1 TISOL Targets

The selection of target material is dictated by the rate of production of the isotope of interest and the release efficiency of the element from the target matrix (see ref. [8]).

The targets presently being considered are given in Table 1, as taken from [9]. This selection of targets is primarily for the production of intense beams of low-Z proton-rich isotopes for injection into the proposed ISOL/Post-Accelerator Facility[10]. The production rates (for use with TISOL) will be limited due to the restriction that the product of beam current and target thickness be no greater than $1 \text{ g}\cdot\text{cm}^{-2} \mu\text{A}^{-1}$. This arises from present shielding configurations. Since required target operating temperatures may be as high as 2500°C , a 500 amp/10 V power supply will be used to heat the target ohmically, supplemented by the proton beam energy.

5.2 Ion Sources

There are four sources to be used during the early stages of TISOL operation: the surface ionization source, the plasma ion source, the Electron Cyclotron Resonance (ECR) ion source and the ISOLDE front end.

The first source to be used on TISOL operates by surface ionization. This technique is particularly useful for the alkali and alkaline elements due to their low ionization potentials[8]. It provides element selectivity, but is limited in the number of elements that can be ionized efficiently. Since this source is simple to make and operate, we plan to use it for the initial testing of the TISOL itself.

The second source to be used on TISOL is a plasma ion source of the Bernas-Nier type which has been designed and built by an ISOCELE/McGill University collaboration (see fig. 5). Such a source has the advantage of good plasma properties combined naturally with a slit geometry for the exit orifice, leading to an efficient and fast release of the ions from the source as well as a small beam emittance. The TISOL plasma ion source features a horizontal slit exit from the ionization chamber. Ionization is achieved by arc discharge. The ionization chamber can accommodate heating of the cathode both directly and by electron bombardment and is capable of handling high beam current. The target chamber also has several important features. The target oven assembly is easily removable and may be heated ohmically independent of the heating of the main chamber. The support gas is fed directly into the target-oven assembly, and the target may consist of

a stack of thin foils. It is expected that the ions will have a short release time due to the (potentially) very high temperature of the target assembly, the absence of a transfer tube, and a carrier gas flow that brings the reaction products directly into the plasma region. The source also has high efficiency due to a large exit area (leading to a faster and much more efficient diffusion of ions from the source, thermal decoupling of the target and ion source chamber (allowing discrimination against less volatile elements when one is interested in high vapour pressure elements), and high current capability (allowing the introduction of reagent gases for on-line chemistry). For further details, see ref. [2].

The third source presently being designed for TISOL is an electron cyclotron resonance (ECR) ion source. It is based on the off-line Karlsruhe ECR source[11] and an on-line version for TISOL is being designed by the SFU group at TRIUMF. It will be used to provide high ionization efficiencies of gaseous low-Z elements such as nitrogen and neon. The details of this design may be found elsewhere in these proceedings[12].

The fourth system is an operational front end, including both targets and different types of ion sources (surface and plasma), which has been obtained from the ISOLDE facility. A picture of this system may be found in ref. [14]. This system has been cleaned, decontaminated, slightly redesigned, and is ready for use.

Another ion source is being designed which will, at a later date, be tested on TISOL. This source employs a resonant ionization technique using

synchronized laser pulses. It is being designed by a group from McGill University and is also described elsewhere in these proceedings[13].

5.3 Services for the Surface and Plasma Ion Sources

The surface and plasma ion sources are designed to fit in a TIS chamber which was designed at McGill University and built at TRIUMF. The service plate for the TIS assembly is mounted on a lifting mechanism so that the plate (and target) may be raised 10 cm (without breaking the vacuum) to allow the proton beam to pass through to the beam dump without intercepting the target. Thus, beam tuning and upstream experiments may be performed without irradiating the TISOL target unnecessarily.

Both the surface and plasma ion sources have a TIS service plate. This plate supports the ion source and is equipped with feedthroughs which carry power, gas, water and diagnostic services for the TIS. The plate and TIS itself are at 20 kV potential to provide the acceleration of the ions. The plate is insulated from the box (which is grounded to the Faraday cage) by a 3.2 cm thick polyethylene flange. The services also sit at HT but for the plasma ion source, their potentials may differ by up to 1 kV. The bundle of cables are carried by a grounded HT trunk that will pass through the shielding to a 2.4 m x 3.6 m Faraday cage located on the platform.

The service plate for the surface ion source is simple. Two 500 amp feedthroughs (in and out) provide the target heating power, while two 250 amps feedthroughs power the ionizer. There are also two feedthroughs for

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two pairs of wires to W-Re thermocouples for measuring the target temperature.

The service plate for the plasma source is much more complex, given the nature of the source itself. The plate has been designed with redundant feedthroughs for additional flexibility. There are feedthroughs for the target heating element, the arc chamber heating element, the mass marker heating element and the anode, as well as two thermocouples, two gas lines and cooling water. There are also two feedthroughs for direct cathode heating, and five for the electron filaments and second cathode used for indirect heating. The 20 kV HT is connected directly to the housing of the power supplies in the Faraday cage and fed to the ion source through its mounting posts. Since the target may operate at very high temperatures, a water-cooled heat shield has been installed inside the TIS box to protect it. The manifold has been designed to allow uninhibited pumping and free passage of the proton and ion beams.

5.4 Extraction Electrode for the Surface and Plasma Ion Sources

The extraction electrode (EE) designed and built for use with the surface and plasma ion sources is shown in fig. 6. The electrode sits at ground potential and is shaped to insure as uniform an electric field as possible over the acceleration region. Although the target chamber may be as hot as 2000°C, the amount of heat radiated through the ionizer slit is sufficiently small that special heat resistant materials are not needed for the EE. The electrode is made of brass and copper, and is chromium-plated

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for easy cleaning. The electrode is followed by steering plates (in the bend plane) and an Einzel lens to increase the angular acceptance of the QQD (within the optical constraints of the QQD itself). The EE-lens system is mounted on a rectangular service plate which connects to the TIS box. For the plasma ion source, this EE system may be insufficient. The magnetic field which holds the plasma tends to steer the beam as it exits the ion source. The height and tilt of the EE may have to be adjusted externally and mechanically to compensate. A second EE support system, which would move the EE, is under consideration. This system has three degrees of freedom: linear motion along the ion beam axis, linear motion along the bend plane axis, and angular motion about the EE slit in the bend plane. A final design has been delayed pending tests with the present EE system.

6. Ion Beam Monitors

A series of beam monitors are to be placed at various points in the system for the purposes of tuning and monitoring. A combination Faraday cup and rotating wire assembly will be mounted after the ion source chamber to either measure the beam current during ion source tuning (destructive monitor) or the ion beam position (non-destructive). The centering of the beam is a particularly important step for the plasma ion source since the magnetic field in the source may steer the beam. Third, a rotating wire scanner will be placed before the dipole to measure the beam profile.

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At the focus, the main monitor will be a Faraday cup behind the main selection slit. The beam profile for several masses is deduced by sweeping the ion source HT and plotting it against beam current. However, this technique stops the beam and cannot be used during normal running in order to monitor the performance of the IS. For masses of $A \leq 40$, more than one mass will be focused in the collection chamber, and a small scanner may be placed on one of the adjacent masses to monitor the performance on-line. For light masses, an alternate method must be found.

7. Control and Interlock Systems

To be consistent with modern procedure, the TISOL will be monitored and controlled by programmable units which are in turn controlled by a main processor (such as an IBM-PC). The system must control (a) the vacuum system, (b) the target-ion source system, (c) the beam line monitors, (d) the beam transport magnets, and (e) data acquisition and display for data analysis and the TRIUMF safety system. At a later stage, the system will also control the secondary transport system (above the shielding blocks).

The system that has been chosen for the TISOL is an "Optomux" with educated unit boards, all connected to two IBM-PC's.

The "Optomux" control system will be deployed in three banks: vacuum system control, TIS control, and beam line system control. The target-ion source control system is the most complex, particularly for the ECR and

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plasma ion sources, which are very complicated devices. The power supplies, thermocouples, and gas and water supplies all sit at 20 kV and are located in the Faraday cage. Thus, the feedthroughs on the matching plate to the ion source only insulate the 10 V of the power supplies, both sides being at HT. For this reason, the "Optomux" bank for the TIS system is also at HT and is in the Faraday cage. Communication with the other banks (which are at ground potential) is through a fiber optic link.

The beam monitors, such as Faraday cups, wire scanners and active slits are also monitored and controlled by the system. The first Faraday cup may receive several milliamps of beam current and thus require cooling, which is also monitored and controlled. The wire scanner before the dipole is a sophisticated device whose movement and readout must be synchronously controlled and analyzed.

The three magnets of the QOD need several control functions. The power supplies' currents must be raised and lowered and the status read out. The magnetic fields are monitored with either Hall or NMR probes and feedback to the power supplies is used to keep the fields constant, independent of the changing temperature of the yoke. In addition, water-cooling of the excitation coils is controlled.

Finally, numerous radiation safety interlocks are monitored and the information sent to the TRIUMF safety control system.

8. Instrument Performance

Presently, the TISOL separator system is being assembled, for off-line testing, on top of the shielding blocks of beam line 4A of TRIUMF. Before the assembly was begun, the dipole was completely field-mapped and the quadrupoles were tested for harmonic content. These results were used in a ray-tracing calculation employing the computer code RAYTRACE[15]. As mentioned in Section 4.2, the optical properties of the dipole turned out to be significantly different from our prediction. In order to achieve a 90° bend, the optical radius of curvature was increased from 1.25 m to 1.31 m, which is closer to the physical magnet curvature (1.38 m). When the quadrupoles were tuned so as to use the entire effective aperture of the dipole, the aberration of the bend plane image was quite large and the focusing in the non-bend plane was too weak to prevent excessive beam loss. Clearly, new pole edges will need to be installed in order to upgrade TISOL to its full potential. In the meantime, we decided to retune the quadrupoles (in the ray-tracing calculations) so as to achieve a beam spot at the focus suitable for the off-line tests.

It was found that in order to achieve suitable optics (with the present dipole configuration), it was necessary to reduce the dipole aperture used and thus increase the magnification of the image in the bend plane (x). A smaller magnification did not reduce the width of the beam spot at the focus (because of increasing aberration), while the larger magnification was necessary to achieve reasonable focusing in the non-bend plane (y).

Because of the large magnification, there is a limit to how much the resolution may be improved by reducing the acceptance in the bend plane (θ_0); that is to say, the contribution to x from θ_0 , by the second-order term (x/θ_0^2), is small compared to (x/x_0) , the magnification, below a certain value of θ_0 . The beam will be collimated in the bend plane in front of the first quadrupole in order to achieve this value. This may be done because the width of the beam at this point is due to its divergence (point source). For the ECR and ISOLDE ion source, a similar technique may also be used in the non-bend plane, since these sources have 1 mm diameter extraction orifices. This is done to minimize beam spill in the pipe at the second quadrupole. The slit configuration of the surface and plasma ion sources means that some beam will be lost.

Table 2 shows the results of three optical configurations: for the surface/plasma source, for the ECR source and for the ISOLDE front end. A calculation of the extraction optics for the first ion source system indicates an initial divergence of ± 20 mr. This value has been assumed for ϕ_0 and yields 82% beam transmission. The transmission drops rapidly for larger ϕ_0 (62% for $\phi_0 = 30$ mr, 46% for $\phi_0 = 40$ mr). The resolution for this system is one third of the value originally planned. The emittance scatterplots in the bend (x, θ) and non-bend (y, ϕ) planes are shown in figs. 7 and 8, respectively. The optics for the ECR source produces a very large bend plane magnification which in turn allows a greater acceptance ($\theta_0 = 40$ mr). The smaller resolving power ($M/\Delta M = 223$) is not a problem, since the source will be used exclusively for light isotopes ($A < 20$). Finally, the

optics for the ISOLDE system are similar to the primary system and should be suitable for all applications during the off-line testing phase.

9. Conclusions

At the present stage, the TISOL is being prepared for the start of off-line tests. In the next few months, tests will be performed using the surface, plasma and ISOLDE ion sources. The ECR source is still under development. The optics of the separator system have been examined and found to be suitable for off-line testing although significant aberrations are present. New dipole pole edge pieces will be designed to minimize these aberrations and should be ready before TISOL is installed on-line. The off-line tests will also afford the opportunity to upgrade and develop the Ion Beam Monitors and the Control System.

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Table 1
Target Materials for TISOL

<u>Isotopes of Interest</u>	<u>Target</u>	<u>Suggested Conditions</u>
Heavy sodiums	Ta TaC Ir	Foils (m.p. 2996° C) Pellets (m.p. 3800° C) Foils (m.p. 2410° C)
Light sodiums	Hf ₃ Si ₃ Al ₄ C ₃ (Al)	Powder (stab to 1400°) Powder (m.p. 660° C) Molten
Light nitrogens	MgO BeO (Na) C	Powder (m.p. 2800° C) Powder (m.p. 2530° C) Molten (m.p. 97.8° C) Graphite powder (3600°)
Heavy nitrogens and neons	TaC Ta Ta ₂ O ₅	pellets (m.p. 3800° C) foils (m.p. 2996° C) powder (m.p. 1800° C)
Light neons	MgO (Na) Al ₄ C ₃ (Al)	Powder (m.p. 2800° C) Molten (m.p. 97.8° C) Powder (stab to 1400° C) Molten (m.p. 660° C)

Table 2
Optical Parameters for TISOL with
Three Ion Source Configurations

IS	x_0 (mm)	θ_0 (mr)	y_0 (mm)	ϕ_0 (mr)	(x/x_0)	(y/y_0)	transmission	x (mm)	y (mm)	$M/\Delta M$
Surface/ Plasma	0.5	30	10	20	6.1	4.4	82%	4.0	32.5	334
ECR	0.5	40	0.5	20	11	2.7	99%	6.0	1.7	223
ISOLDE	0.5	30	0.5	15	5.0	2.0	100%	4.0	1.3	334

The first four columns are the initial acceptances, followed by the bend and non-bend plane magnifications, the beam transmission, the image width and length, and the mass resolving power.

Figure Captions

1. Plan view of the TISOL in its future on-line position. The dipole sits in its own area which may be isolated from the rest of the facility containment room.
2. Elevation view of TISOL in its future on-line position. The beam pipe passes through a hole in the concrete shielding between the 3.6 and 4.8 m levels.
3. View of the TISOL in its off-line position on top of the shielding at the 6.1 m level. The Faraday cage is shown on the platform at the top of the picture. At the right is the TIS chamber which houses the surface and plasma ion sources. The surface source is standing on a box at the bottom-right-hand corner of the picture.
4. Plan view of the future experimental area. The vertical beam is bent 90° and sent to several experimental areas by means of electrostatic lenses and deflectors.
5. Side view of the ISOCELE/McGill plasma ion source. (1) Ta gas line (2) stainless steel post (3) brass cooling plate (4) Ta posts (5) thermocouple (6) stainless steel box (7) stainless steel cover (8) Mo front plate (9) target-oven assembly (10) exit slit (11) cathode (12) main heating element.
6. Extraction electrode used with the surface/plasma ion sources. Behind the electrode are bend plane steering plates and an Einzel lens.

7. Bend plane emittance plot at the focus for the surface/plasma ion source configuration. The parameters are $x_0 = \pm 0.5$ mm and $\theta_0 = \pm 30$ mr for an overall acceptance of 15π mm-mr. The image parameters are $x = \pm 4$ mm and $\theta = \pm 5$ mr for a resolving power of $M/\Delta M = 334$.
8. Non-bend plane emittance plot at the focus. The object parameters are $y_0 = \pm 10$ mm and $\phi_0 = \pm 20$ mr for an overall acceptance of 200π mm-mr. The image parameters are $y = \pm 32.5$ mm and $\phi = \pm 8$ mr.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 7

- C
- Ta
- BN
- brass
- St. St.
- Mo

Fig. 5

Fig. 6

Fig. 8