RESEARCH AND DEVELOPMENT STUDIES WITH RADIOACTIVE BEAMS AT TRIUMF

J.M. D'Auria[1], M. Dombsky[1], L. Buchmann[2], H. Sprenger[2], J. Vincent[2], J. King[3], P. McNeely[4] and G. Roy[4]

[1]Dept. of Chemistry, Simon Fraser University, Burnaby, B.C. Canada, V5A 1S6
[2]TRIUMF, 4004 Wesbrook Mall, Vancouver, B.C. Canada, V6T 2A3
[3]Dept. of Physics, University of Toronto, Toronto, Ontario, Canada, M5S 1A7
[4]Dept. of Physics, University of Alberta, Edmonton, Alberta, Canada, T6G 2E9

ABSTRACT

In 1985 a detailed conceptual plan was proposed for the installation at TRIUMF of a high intensity accelerated radioactive beams facility (ISAC) involving an on-line isotope separator and a LINAC post-accelerator. Masses up to A=60 were to be accelerated to energies between 0.2 and 1.5 MeV/u and the facility devoted mainly to studies in nuclear astrophysics. While awaiting a decision on this proposal, a prototype isotope separator, TISOL, has been successfully installed and is now available as a limited production facility, servicing an experimental program. This paper will provide a status of the ISAC proposal, a general description of the TISOL radioactive beams facility now operating at TRIUMF, and a summary of the future plans of these programs including a revised ISAC proposal.

1. INTRODUCTION

The TRIUMF cyclotron is an optimal facility for the intense production of a wide range of radioisotopes, which can then be accelerated appropriately to result in a low energy radioactive beams facility. This was recognized some years ago as a proposal was submitted in 1985 to install a high intensity, accelerated radioactive beams facility at TRIUMF. This low energy, facility (ISAC) was to consist of an on-line isotope separator followed by a LINAC post-accelerator to boost the energies of the separated radioisotopic ion beams to 1.5 MeV/u.[1,2)] This was the pioneer proposal of the two accelerator type which has now spawned a number of similar proposed or operational facilities. ISAC was delayed due to the presense of the KAON proposal, but TRIUMF did authorize the installation of a thick target, on-line separator (TISOL) for research and development studies with radioactive beams. The TISOL facility has been in operation for several years both as a test system and now as a production facility servicing a modest experimental program. Based upon the experience and expertise developed with TISOL, and depending upon a final decision on KAON, a revised ISAC could be implemented at TRIUMF. A description of the TISOL facility will be presented herein along with aspects of the experimental and developmental program; a conceptual plan for a revised ISAC will also be described.

2. THE TISOL FACILITY

2.1. General Description

TISOL is a vertically mounted, thick target, on-line isotope separator located at the 500 MeV proton facility, TRIUMF. Such energetic protons are ideal for the production of a wide range of radioisotopes, and the thick target combined with the high intensity of the TRIUMF beam leads to relatively high production rates for the resulting radioactive nuclear beams. Figure 1 displays an elevation view of TISOL as it exists today, having evolved from a much smaller version which was installed originally.[3)] The target is positioned just before the beam dump and beam intensities up to 1.5 μA can be used. Target handling has been performed mainly by personnel up to now, but a new remote target changing system is being installed to allow for changing of the very hot target systems. A halo monitor is used upstream of the target to monitor the beam position while a secondary electron emission monitor is located behind the target to monitor the proton beam intensity. A new experimental area with the three beam lines is located at ground level, well shielded from proton beam radiation. A detailed description of the facility can be found elsewhere.[3–6)]

2.2. Ion Sources

There are presently two working ion sources available at TISOL, an ECR (Electron Cyclotron Resonance) source and a standard heated surface, thermal source; these have been described in detail elsewhere.[5,6)] While the latter source does provide some degree of elemental selectivity (species of low ionization potentials) in its ionization, the ECR source will ionize any species, elemental or molecular, which reaches it, to a range of charge states, e.g., recently the isotope ^{18}N was observed at a

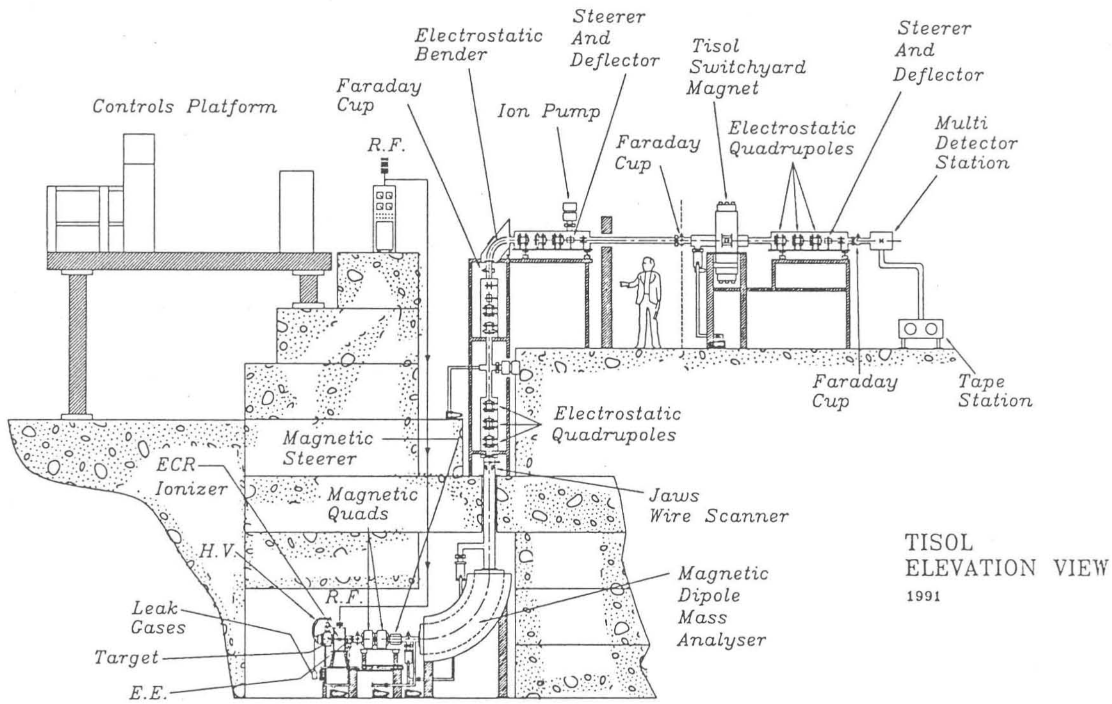

Fig. 1. Elevation view of TISOL.

mass position of 16 as the species $(^{18}N^{14}N)^{++}$. Some selectivity can be obtained by using a non-heated transfer line between the source and the target, eliminating non-volatile species.

Improvements are planned to allow for ion changes quickly (one hour), and this combined with the target changing system will further reduce personnel doses. The ECR system will also incorporate ceramic insulating flanges.

2.3. Target Materials and Radioactive Beams

A range of target materials have been used at TISOL and these are summarized in Table 1. Ion beams of radioactive isotopes from all of these elements have been observed. Intensities vary depending upon the target, its thickness, the reaction involved, the stability of the species and operating parameters of the facility; intensities as high as 10^9 p/sec per μA of production proton beam have been observed. Observed production rates can be found elsewhere.[4–6]

The zeolite (commonly called molecular sieve) target material is unique for an ISOL target. The type used here is 13X ($NaA1SiO_4$) and has openings of the order of nm. The target elements are optimal for producing low Z products on both sides of stability. In order to be useful as a target, it must be heated under vacuum for several days and the temperature should not exceed about 600°C to prevent break-down of the structure. This material, when properly conditioned, has proven to be optimal for the production of nitrogen beams when coupled with the ECR source; oxygen, carbon and helium beams

Table 1.

Target Source	Form	Operating Temp (°C)	Elements Observed
			a) ECR Source
A1N	Powder	1050	He,Ne,N
CaO	Chunks	1100	C,He,Se,N
CaO	Powder	1100	Ar,C,Ne,N
LaC_2	Chunks	1700	He,Ne,Xe
MgO	Chunks	1300	C,He,Ne,N
MgO	Pellets	1300	C,Ne,N
MgO	Powder	1300	C,Ne,N
$Mg^{18}O$	Powder	1300	C,He,Ne,N
SiC	Pellets	1500	Ne,O
Ti	Foils	1500	Ne,Ar,Cl,He
UO_2/C	Pellets	2000	C,Kr,He,Xe,Se,O,Sn
Zeolite*	Spheres	500	Ar,C,He,Ne,N,O
			b) Re Surface Source
Hf	Foils	1800	Cs,K,Li,Na,Rb,Yb
Nb	Foils	1900	K,Li,Na,Rb,Sr
Nb	Powder	2000	Rb
SiC	Pellets	1500	Al,Li,Na
Ti	Foils	1500	Al,K,Li,Na
Ti	Foils	1500	Al,K,Li,Na
$U0_2$/C	Pellets	2000	Al,Cs,Ga,In,Li,Na,Rb
Zr	Foils	1000	K,Na,Rb,Sr
ZrC	Pellets	2000	Al,K,Li,Na,Rb,Sr

*($NaAlSiO_4$)

have also been observed. The cation, e.g., Na^+ for 13X, can be exchanged relatively easy for heavier substances and this material could then be used for heavy A, radioactive beams production.

2.4. The Experimental Program

The TISOL facility is now also used as a production facility, servicing an experimental program. There are now five approved studies and a brief summary of some is given herein.

While Exp. 617 (Studies of Light Rb Isotopes) has obtained publishable results in 1991, problems in the data acquisition system have forced remeasurement this year. Significant results have been obtained for Exp. 589, a major experimental study on the beta delayed alpha emission of ^{16}N. This decay is the inverse of the important astrophysical reaction, $\alpha + {}^{12}C$, and approximately 4 weeks of continuous use of TISOL have resulted in the observation of new, important results.[7] The new zeolite target released the highest yields of ^{16}N available anywhere, and over 1.25 × 106 coincidence events (^{12}C and α) have been observed.

3. FUTURE GOALS

3.1. Future Plans at TISOL

It is difficult to describe future plans without reference to the proposed KAON facility at TRIUMF. It is planned to continue with research and development studies on TISOL, independent of the final decision on KAON. If KAON is finally funded properly, the TISOL facility can continue in its present location as beam line 4A should still be in operation although at a slightly lowered beam energy (450 MeV) and in intensities up to 15 μA.

In the planning and development of the suggested ISL (IsoSpin Laboratory),[8] it is expected that TISOL will be available for target development studies using proton beam intensities up to 10 μA. These studies would be in addition to the continuation of the present TISOL scientific program mentioned above.

3.2. A Revised ISAC Facility

In the scenario of a positive decision on KAON, there is a possibility that an ISAC facility will be considered for installation on the 3 GeV beam line. Figure 2 presents a layout of the revised ISAC. However, given the large manpower demands and costs of KAON, this has to be considered remote. In the case of a negative, final decision on KAON, there is a good possibility that ISAC will be a centerpiece of the new TRIUMF facility. Considerations thus have been given to the previous ISAC proposal and possible changes depending upon the previous ISAC proposal, the world situation in the field of accelerated radioactive beams, and the interest shown by potential users, especially in North America. It is important to preface any such remarks by a close look at the reasons why TRIUMF is considered a good location for ISAC.

3.2.1. Why at TRIUMF?

It is important to indicate clearly the advantages of locating a low energy, high intensity accelerated radioactive beams facility at TRIUMF. The presence of the high intensity, 500 MeV proton facility makes it the obvious choice, since thick targets can be used leading to high production rates. The personnel at TRIUMF are also quite experienced in working with the very high radiation fields expected to be generated by the ISOL device when using beams up to 100 μA. This gives this lab a considerable edge when compared to labs who may have possible post-accelerators on site but lack such experience. TRIUMF has developed expertise in working with such thick target facilities given the presence of the TISOL facility. Finally, the TRIUMF cyclotron itself is an important consideration. It is a reliable, cost-effective machine which produces an essential CW beam, ideal for ISOL types of targets, with good beam emittance properties. Several beams can be extracted simultaneously which allows for beam availability to several high priority facilities.

3.2.2. Specifications

The specifications for the revised ISAC facility are presented in Table 2 and have been developed over a period of years. It is believed that these specifications are all technically achievable with either presently existing technology or with some modest upgrades in present systems.

3.2.3. Research and Development Areas (TISOL and Elsewhere)

Certain areas do require some developmental studies prior to finalizing the design of ISAC. These include:

- development of a low beta, RFQ accelerating structure for CW operation;
- development and test of a thick target which can handle high proton beam intensities;
- optimization of an ECR ion source to produce high relative yields of multiply charged ions of masses with A>60;
- development of an optimal stripping system for such low intensity, low energy beams.

Some of these activities can be done on the TISOL facility which must remain as a test and experimental station during construction of ISAC. In addition, various labs around the world have indicated their willingness and interest to collaborate in such studies including LAMPF, CRNL, Argonne, ISL, and Oak Ridge.

Table 2: Specifications for ISAC (Revised)

Production System		
Projectile	-	protons (200-500 MeV)
Intensities	-	<100 μA
Target Stations	-	2
Target Thicknesses	-	20 cm
Products	-	A<240, Z<93
Separation System		
Ion Sources	-	for charge state, Q = 1± [plasma, thermal, ECR]; for q>1+ charge states, [ECR];
Mass Separators	-	two medium mass resolution systems with two mass beams extractable; one high mass resolution (M/M=30,000)
Extraction Voltage	-	60 kV
Post Acceleration System		
Injection Specs	-	E = 60 keV, q/A>1/60
Output Energy	-	variable, 0.2–10 MeV/u
Energy Resolution	-	<1%
Energy Increments	-	<0.1%
Mass Range	-	A<60–(A>60 for q>1+) expandable up to A = 240 (q/A = 1/240)

4. CONCLUSION

TRIUMF remains active in the field of radioactive beams with the operating TISOL facility. With a decision on KAON, the future of the proposed ISAC, the high intensity, low energy, accelerated radioactive beams facility of the ISOL/PA type can then be ascertained.

5. REFERENCES

1) Buchmann, L., D'Auria, J.M., King, J.D. Mackenzie, G., Schneider, H., Moore, R.B. and Rolfs, C., Nucl. Instrum. Meth. in Phys. Res. **B26**, 151 (1987).
2) Proposal, "The TRIUMF-ISOL Facility: A Proposal for an Intense Radioactive Beams Facility", submitted to TRIUMF, June 1985.
3) Oxorn, K. *et al.*, Nucl. Instrum. Meth. **B26** (1987).
4) Dombsky, M. *et al.*, Nucl. Instrum. Meth. **A295**, 291 (1990).
5) Buchmann, L., Vincent, J., Sprenger, H. Dombsky, M., D'Auria, J.M., McNeely, P. and Roy, G., Nucl. Instrum. Meth. **B62**, 521 (1992).
6) Dombsky, M., Ph.D. Thesis, Simon Fraser University, 1991.
7) Buchmann, L. *et al.*, "The β-delayed α spectrum of ^{16}N and the low-energy extropolation of the $^{12}C(\alpha,\gamma)^{16}O$ cross section; submitted to Conf. on Chaos in the Cosmos, Karlsruhe, Germany, July 1992, preprint.
8) "The IsoSpin Laboratory: Research Opportunities with Radioactive Nuclear Beams", prepared by the North American Steering Committee for the ISL Laboratory, LALP 91-51 (1992).

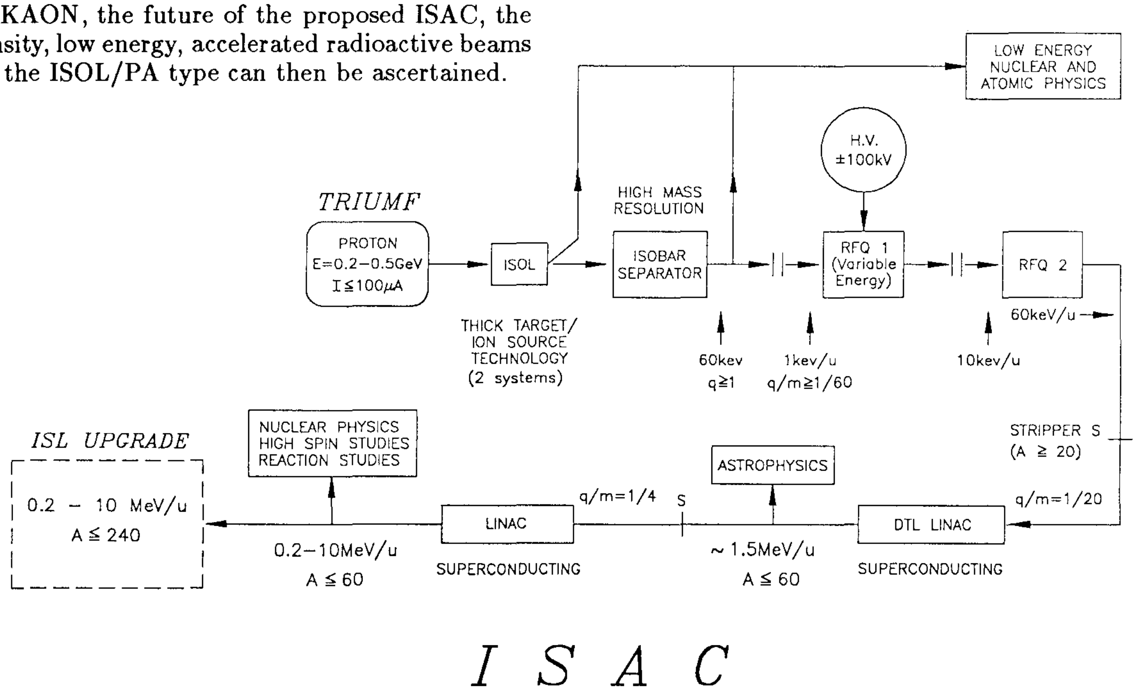

Fig. 2. Schematic representation of a revised ISAC Facility