REVIEW OF ISOL-TYPE RADIOACTIVE BEAM FACILITIES

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Abstract

The ISOL technique was invented in Copenhagen over 50 years ago and eventually migrated to CERN where a suitable proton drive beam was available at the Synchrocyclotron. The quick spread of the technique to many other laboratories has resulted in a large user community, which has assured the continued development of the method, physics in the front-line of fundamental research and the application of the method to many applied sciences. The technique is today established as one of the main techniques for on-line isotope production of high intensity and high quality beams. The thick targets used allow the production of unmatched high intensity radioactive beams. The fact that the ions are produced at rest makes it ideally suitable for low energy experiments and for post acceleration using well established accelerator techniques. The many different versions of the technique will be discussed and the many facilities spread all over the world will be reviewed. The major developments at the existing facilities and the challenges encountered will be presented. Finally, the possibility of using the resulting high intensity beams for the production of intense neutrino beams will be briefly discussed.

INTRODUCTION

In a major review paper in the book, “Treatise on heavy ion science” [1], B. Allardyce and H. Ravn gives the following definition for Isotope Separation On-Line (ISOL): “Such an instrument is essentially a target, ion source and an electromagnetic mass analyzer coupled in series. The apparatus is said to be on-line when the material analyzed is directly the target of a nuclear bombardment, where reaction products of interest formed during the irradiation are slowed down and stopped in the system”. Strictly speaking that puts all methods, including In-Flight production (IF) with stopping in a gas-cell, in which the radioactive ions are stopped before being re-accelerated, in the same category. However, classically the ISOL method has been associated with thick targets in which the reaction products are thermalised in the target itself and diffuse out to an ion source for further acceleration and separation. This paper will focus on the ISOL production in thick targets and other methods will just be mentioned for reference purposes.

THE ISOL TECHNIQUE

The great advantage of the thick targets is the large total cross-section available for production of ions. Three main reaction channels are responsible for the bulk production of ions: spallation, fragmentation and fission, Fig. 1. In ISOL facilities with neutrons as the “driver beam” the two first channels are suppressed leading to a lower cross section but a higher beam purity. The disadvantage with ISOL production in general is the general difficulty to achieve high beam purity due to the many isobars of different elements produced simultaneously in the target. High beam purity can only be achieved with a combination of measures such as the right choice of target material, driver beam and ion source. Furthermore, refractory elements are in general difficult to produce due to the high temperatures required to make them volatile.

A schematic representation of the ISOL method and the major associated loss channels are shown in Fig. 2. An active target and ion source development programme is crucial for the success of any ISOL facility. The aim of such a program is to reduce the losses while maximize the production without further deterioration of beam purity.
RADIOACTIVE NUCLEAR BEAMS (RNB)

The future challenges for nuclear physics will require radioactive beams and not only isotopes at rest. After pioneering work at Louvain-la-Neuve in the 1990s [2] the technology for the post acceleration of radioactive ions has recently started in earnest and several facilities are now becoming operational. The major challenges encountered are the adaption of the time structure of the beam, the need to increase the charge state for economic accelerating systems and the low intensities compared to similar systems for stable beams.

FIRST GENERATION ISOL FACILITIES

Existing facilities

There are a number of first-generation ISOL facilities in Europe and elsewhere in the world (see Fig. 3), and their main characteristics are listed in Tab. 1. They have rejuvenated Nuclear Physics by giving rise to many unexpected, exciting and important scientific discoveries, but the in-flight facilities developed from existing stable-beam machines have limitations, and the ISOL complexes generally deliver weak intensities and have modest post-accelerating capability. The advancement of the related science will soon be hindered without new and vigorous investment. It is necessary to improve by orders of magnitude the intensities of the currently available ions, and to offer a vast range of new beams further away from stability as well as more efficient instrumentation.

Intermediate facilities

The main limiting factors for carrying out cutting-edge research at the present ISOL facilities are threefold: (i) the driver beam intensity, (ii) the target and ion-source technology and safety related issues and (iii) the energy of the post-accelerated beams. The first two limit the intensity and ‘exoticity’ of the available beams, while the third limits the scope of the research methods that can be utilized. Major advances in these three areas will give access to new and unique research opportunities, as detailed in, the EURISOL RTD report [3]. This preliminary feasibility study also demonstrated that the technical advances necessary before the construction stage can be envisaged are numerous and challenging. Therefore the European nuclear science community has established a detailed roadmap for reaching the ultimate ISOL facility. This road map encompasses three requirements: (1) optimal exploitation and upgrading of the current European ISOL facilities indicated in Tab. 1, in particular REX-ISOLDE [8] and SPIRAL; (2) construction of intermediate facilities such as SPES [4], SPIRAL II [6], and MAFF [7], shown in Tab. 2; and (3) detailed feasibility studies and technical preparatory work of the most challenging components for the ultimate ISOL facility, to be carried out in the framework of design studies.

FUTURE FACILITIES

Concurrently with the building of these intermediate facilities, the on-going studies of RIA [12] and EURISOL will cover aspects specific to the design and implementation of the next-generation facility, which is expected to encompass the combined advances of the mid-term realizations, while pushing them to a qualitatively higher level. This original strategy would provide Nuclear Physicists with radioactive ion beams of unmatched intensity, variety and quality. These would be a major component of the worldwide supply of RIBs, as indicated in Tab. 3. The EURISOL facility will include the development of a liquid
metal neutron converter which will push this technology to its ultimate with an estimated maximum of 5 MW of primary beam power.

**THE BETA-BEAM**

The beta-beam facility [13, 14], see Fig. 5, could provide the neutrino physicist with electron (anti-) neutrino beams of unmatched intensity making it possible to probe issues such as CP violation in the weak sector [15]. The study of a beta-beam facility figures as an integral part of the proposed EURISOL design study and is described elsewhere in these proceedings [16].

**CONCLUSIONS**

The world wide quest for intense radioactive beams for nuclear physics and its applications is driving the development of a new generation of radioactive beam facilities in the world. A number of intermediate facilities will serve as test benches for the technology to be deployed in the future facilities. The beta-beam option is an interesting synergy
with the high energy physics world and could also result in unprecedented intensities of high energy radioactive beams suitable for IF production of even more exotic radioactive beams.

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REFERENCES

Table 3: Future ISOL RNB facilities

<table>
<thead>
<tr>
<th>Location</th>
<th>Driver</th>
<th>Post-accelerator</th>
<th>Type of facility</th>
</tr>
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<tbody>
<tr>
<td>Europe: GSI</td>
<td>synchrotron</td>
<td>-</td>
<td>In-Flight</td>
</tr>
<tr>
<td>Germany</td>
<td>heavy ions: 1.5 A GeV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Europe: EURISOL</td>
<td>CW linac, protons</td>
<td>CW Linac</td>
<td>ISOL</td>
</tr>
<tr>
<td></td>
<td>1 GeV, 1-5 MW</td>
<td>up to 100 A MeV</td>
<td></td>
</tr>
<tr>
<td>USA: RIA</td>
<td>900 MeV protons</td>
<td>Linac up to</td>
<td>ISOL, In-Flight</td>
</tr>
<tr>
<td>Rare Isotope Accelerator</td>
<td>heavy ions: 400 A MeV, 100 kW</td>
<td>815 A MeV</td>
<td></td>
</tr>
<tr>
<td>JAPAN: RIKEN</td>
<td>Ring-cyclotrons</td>
<td>storage and cooler rings</td>
<td></td>
</tr>
<tr>
<td>RIB Factory</td>
<td>up to 400 A MeV (light ions)</td>
<td></td>
<td>In-Flight</td>
</tr>
<tr>
<td></td>
<td>up to 150 A MeV (heavy ions)</td>
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[16] M. Benedikt, S. Hancock and M. Lindroos, see these proceedings