SPES PROJECT: A NEUTRON RICH ISOL FACILITY FOR RE-ACCELERATED RIBS

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Abstract

SPES (Selective Production of Exotic Species) is an INFN project with the aim to develop a Radioactive Ion Beam (RIB) facility as an intermediate step toward EURISOL. The SPES Project is under realization at the INFN Legnaro National Laboratories site. The SPES Project main goal is to provide a production and accelerator system of exotic beams to perform forefront research in nuclear physics by studying nuclei far from stability. The SPES Project is concentrating on the production of neutron-rich radioactive nuclei with mass in the range 80-160. The final energy of the radioactive beams on target will range from few MeV/u up to 11 MeV/u for A=130. The SPES facility acceleration system will be presented.

INTRODUCTION

The aim of the SPES project is to provide relatively high intensity and high-quality beams of neutron-rich nuclei to perform forefront research in nuclear structure, reaction dynamics and interdisciplinary fields like medical, biological and material sciences. SPES [1] is a second generation ISOL radioactive ion beam facility. The SPES project is part of the INFN Road Map for the Nuclear Physics; it involves the Italian national laboratories LNL (Legnaro) and LNS (Catania).

It is based on the ISOL method with an UCx Direct Target able to sustain a power of 10 kW. The primary proton beam is delivered by a cyclotron accelerator with an energy of more than 40 MeV and a beam current of 200 μA. Neutron-rich radioactive ions will be produced by Uranium fission at an expected fission rate in the target of the order of 10^{13} fissions per second with an expected rate on the secondary target of 10^{8} pps.. The exotic isotopes will be re-accelerated by the ALPI superconducting LINAC.

THE SPES PROJECT

General Layout

The SPES project foresees the construction of new facilities on the LNL site as shown in Fig. 1. The SPES building blocks are: a primary proton accelerator; an ISOL source; the beam selection and transport line and the first part of the secondary beam accelerator needed as injector in the existing LNL superconducting accelerator ALPI.

As a primary proton beam accelerator it was decided to acquire a cyclotron from a commercial company in order to focus on the design and the production of the beam transfer and selection line and of the front end accelerator for ALPI.

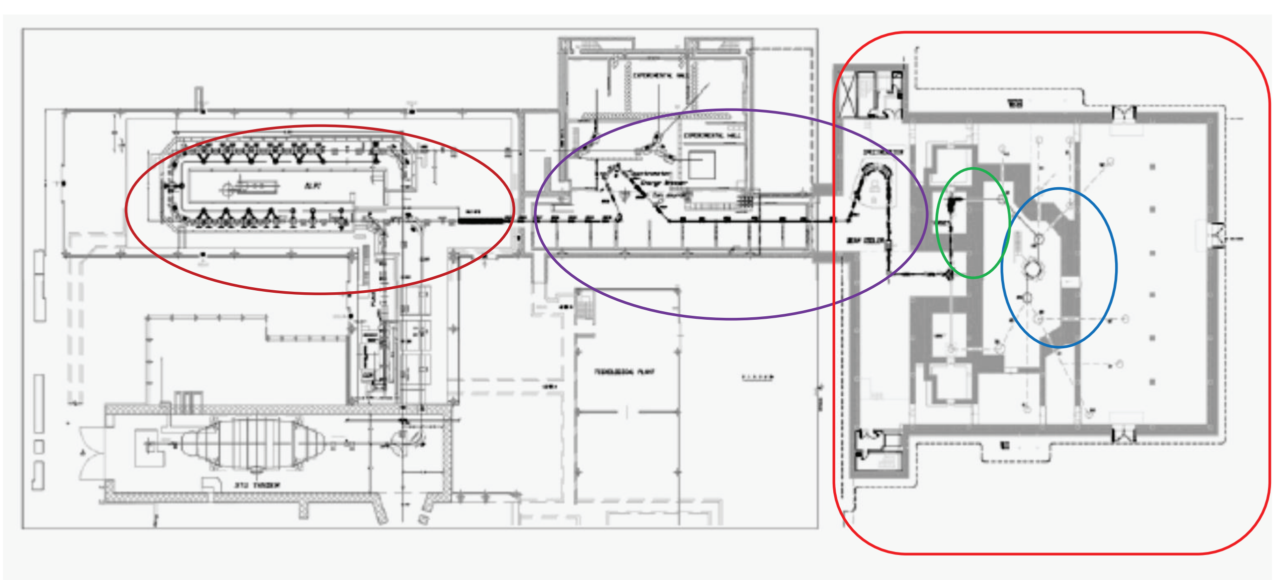

Figure 1: The LNL accelerator complex layout. Starting from the right hand side in the square there is the new building still under construction, inside the ovals in sequence there are from the right hand side: the Cyclotron, the RIB's source, the beam selection and transport line and the re-accelerator which is under construction, namely the RFQ.

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Table 1: Technical Specification of the SPES Cyclotron

Component	Technical Figures
Main Magnet	Bmax field: 1.6 T Coil current: 127 kAT 4 sectors, deep valley Hill sector angle: 50 °
RF cavity	Frequency: 58 MHz Harmonic: 4th Dee voltage: 60-81 kV Dee angle: 36 °
External ion source and injection line	Multi-cusp H-, 15-20 mA DC Accelerated Beam current: 750µA Spiral inflector
Vacuum	Ion source: $<1\times10^{-5}$ torr Main tank: $< 1\times10^{-7}$ torr
Extraction	Simultaneous dual beam 2 stripping multi-foil carousels Variable energy 35-70 MeV

After the bid the BEST Theratronics Company was chosen, which proposed a Cyclotron with the technical specs reported in Table 1.

All the other components of the project will be designed and realized in house or in collaboration with Scientific Partner such as LPCS Grenoble for the Charge Breeder.

The Proton Driver: The Cyclotron

The BEST Cyclotron is a compact four sector machine, energized by a pair of room temperature conducting coils. The cyclotron is able to accelerate H^- beam, provided by an external multi-cusp ion source, up to the energy of 70 MeV. Since the proton extraction is done by the stripping process, the final energy varies within 35-70 MeV. Two independent extraction channels placed at 180° one respect to the other provide the simultaneous extraction of two beams. The maximum beam current deliverable is estimated to be 750 µA.

The external ion source and provides the H^- beam with a current of about 15-20 mA in order to deliver at the exit of the cyclotron a final current of 750 µA or more.

The injection of the beam into the cyclotron is by mean of a axial transport line upwards to the spiral inflector which bends beam 90° into the central region at the median plane.

The high intensity cyclotron is designed to deliver proton with energy in the range 35-70 MeV. The cyclotron will be equipped with two extraction combination magnets, placed at 180° one respect to the other.

The main magnet is described in Ref. [2] and the RF system in Ref. [3].

The RIB's ISOL Source

The interaction of the proton beam with the UCx target will produce fission fragments of neutron-rich isotopes that will be extracted by thermal motion and ionized at 1^+ charge state by a source directly connected with the production target [4]. The hot-cavity ion source chosen for the SPES project was designed at CERN (ISOLDE). The source has the basic structure of the standard high temperature RIB ion sources employed for on-line operation. The ionizer cavity is a W tube (34 mm length, 3 mm inner diameter and 1 mm wall thickness) resistively heated to near 2000°C. The isotopes produced in the target diffuse in the target material and after that will effuse through the transfer tube (its length is approximately 100 mm) into the ionizer cavity where they undergo surface or laser ionization. The Surface ionization process can occur when an atom comes into contact with a hot metal surface. In the positive surface ionization, the transfer of a valence electron from the atom to the metal surface is energetically favorable for elements with an ionization potential lower than the work function of the metal. For alkalis and some rare earth elements, high ionization efficiencies can be achieved using the surface ionization technique. This 1+ source has good efficiency and selectivity for the elements as Rb, Cs, Ba. For most of the others elements, laser resonant photo-ionization, using the same hot cavity cell, is a powerful method to achieve sufficiently selected exotic beams. This technique, under development, is being implemented with the aim to produce beams as pure as possible (chemical selectivity) also for metal isotopes. To ionize elements with high ionization potential, as rare element gasses a plasma source is needed. This source ionizes all the elements without any selectivity. At SPES both surface and plasma sources are developed and in operation at the off line test stand. The laser source is under development.

The Beam Selection and Transport Line

The first mass selection is performed by a Wien Filter with 1/100 mass resolution, installed just after the first electrostatic quadrupole triplet inside the production bunker with the aim to confine the larger part of radioactivity inside the high shielded area. The transfer line toward ALPI is equipped with several beam handling systems to purify the beam: a Beam Cooler and a High Resolution Mass Separator (HRMS) with 1/20000 mass resolution will be installed inside the new building. A crucial task for the experiment with radioactive beams is not only the beam intensity but also the beam quality. Special efforts have been dedicated to design a mass spectrometer with an effective mass resolution of at least

1/20000. Such design takes advantage of a Beam Cooler, to improve the beam emittance, and of a 260 keV HV platform on which the mass separator is mounted. The mass separator is a scaled-up version of the separator designed for CARIBU, Argonne. In the SPES configuration the physics design gives a resolution on the order of 1/40000 constrained by an emittance of 3 π mm mrad and energy spread of 1.3 eV. Such high selectivity results in an advantage also for the safety issue, reducing the problems of contaminations along the beam transport area, re-accelerator and final target location.

Before the injection in the ALPI Linac it is necessary to increase the charge state from 1+ to n+ for an effective reacceleration. This is performed by means of a Charge Breeder. The SPES Charge Breeder is based on ECR method and aims to produce ions with A/q less than 6 at A~130. The design and construction will be performed in the framework of the SPES-SPIRAL2 collaboration at LPCS (Grenoble, France) following an up-graded version of the Phoenix booster in operation at LPSC.

After the Charge Breeder a second mass separator with 1/1000 mass resolution, will be installed to clean the beam from the contaminants introduced by the Charge Breeder itself (CB-MS). The same basic configuration of HRMS is adopted. Finally an RFQ pre-accelerator will increase the beam energy to match the ALPI acceptance.

The Secondary Beam Re-acceleration

This part will be design and realized in house by the LNL staff based on its large experience in LINACS.

The SPES injector for ALPI includes a new RFQ [5] that will operate in a CW mode (100% duty factor) at a resonant frequency of 80MHz. This frequency is the same as that of the superconducting structures of the lowest energy section of ALPI. The injection energy of ions was set to 5.7 keV/u. This choice is a compromise between the desire to reduce the ion energy to simplify the LEBT and the RFQ bunching section design and the need to increase the beam rigidity in the 1+ transport line to reduce space charge effects. The extraction energy of the RFQ was set to 727 keV/u to optimize the beam dynamics of the superconducting linac ALPI.

THE SPES STATUS AND SCHEDULE

The Project is now in its realization stage. The building work started in February 2013 and is on schedule. The cyclotron and its ancillary systems are under test at the BEST Theratronics Ottawa and its beam line to direct the beam to the source is under construction. All the other components and the refurbishment of the LNL accelerator complex started.

The SPES up to date schedule is shown in Table 2.

Table 2: SPES Schedule

	2012	2013	2014	2015	2016	2017
Authorization to operate and safety	UCx 5μA	Full UCx authorization				
ISOL Target-Ion Sources development						
ISOL Targets construction and installation						
Building Construction	project					
Cyclotron Construction & commissioning						
RFQ development and Alpi up-grade						
Design of RIB transport & selection						
Installation of RIBs transfer lines						
Commissioning and first exotic beam						

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REFERENCES

[1] G. de Angelis, A. Andrighetto, G. Bassato, L. Biasetto, L. Calabretta, M. Comunian, A. Galatà, M. Giacchini, F. Gramegna, A. Lombardi, M. Manzolaro, G. Prete, L. Sarchiapone, D. Scarpa, D. Zafiropoulos and the SPES collaboration, "Future Perspectives of the Legnaro National Laboratories: The SPES project", Journal of Physics: Conference Series 267 (2011) 012003.

[2] Fred Samson Grillet, Bruce Forrest Milton, Darcy Montgomery, "Magnetic Field Mapping of the Best 70 MeV Cyclotron", Cyclotrons 2013, Vancouver, Canada, TUPSH009, these proceedings.

[3] Vasile Sabaiduc, Graham Gold, Benjamin Albert Versteeg, Julio Cesar Panama, "Resonator System for the BEST 70 MeV Cyclotron", Cyclotrons 2013, Vancouver, Canada, TU2PB04, these proceedings.

[4] Andrighetto, L. Biasetto, M. Manzolaro, D. Scarpa, J. Montano, J. Stanescu, P. Benetti, I. Cristofolini, M.S. Carturan, P. Colombo, P. di Bernardo, M. Guerzoni, G. Meneghetti, B. Monelli, G. Prete, G. Puglierin, A. Tomaselli, P. Zanonato, "Production of High-intensity RIB at SPES", Nuclear Physics A 834 (2010) 754c–757c.

[5] M. Comunian, A. Palmieri, A. Pisent, F. Grespan, "The RFQ Injector for the Radioactive Ion Beam of SPES Project", LINAC 2012, Tel-Aviv, Israel.

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