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The SPES exotic beam ISOL facility: Status of the project, technical challenges, instrumentation, scientific program

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Summary. — The SPES facility (Selective Production of Exotic Species), that is the INFN project for a Nuclear Physics facility with Radioactive Ion Beams (RIBs) is in advanced construction at the Legnaro National Laboratories. It will mostly provide neutron-rich exotic beams, through the production of fission fragments (10^{13} fiss/s) by an intense proton beam ($200\,\mu$A) on a direct UCx target. Several other targets will be developed, in order to provide users a large beam selection. Forefront research in nuclear structure and dynamics will be performed in the forthcoming years, studying a nuclear chart region far from stability. The expected beam intensities, their quality and their maximum available energies (up to 11 MeV/n for $A \simeq 130$) will provide the users with a modern and highly perfomant facility. Coordinated efforts are being dedicated to the developments and upgrading of both the accelerator complex and of up-to-date experimental set-ups.

(*) On behalf of the SPES Collaboration.

1. – Introduction

Advanced scientific infrastructures are needed to progress in many fields of science, and they are overall important in nuclear and sub-nuclear physics. In particular, the construction of still more powerful radioactive beam facilities allows to deeply advance in understanding nuclear structure. Moreover, using post-accelerated radioactive beams even nuclear reaction studies can be performed, which enlarge the knowledge of nuclear matter far from stability. One of such new facility is SPES, the INFN RIB infrastructure, which is under construction at the Legnaro National Laboratory in Italy [1]. The layout of the facility is shown in fig. 1. The project was born few years ago with the intent to construct a multipurpose facility. Four different phases were in fact defined: α-phase - construction of the main building and installation and commissionig of a proton driver based on a high intensity (up to $750\,\mu$A) 70 MeV commercial cyclotron; β-phase - construction of a RIB facility with a low energy area (non reaccelerated beams) and a post-acceleration beam facility, by upgrading the ALPI Linac of LNL; γ-phase - related to the development of two areas: on one side the RILAB activity, to which a bunker is dedicated, where research on new radio-isotopes production will be performed and where the activity will be dedicated to cross section measurements, high power new target tests, radioisotope production tests and connected tests of radio-pharmaceuticals; on the other end, a production facility in collaboration with a private company is going to be defined and to be operated in the RIFAC bunker and related pharmaceutical laboratories; this part is under discussion for a cooperation between INFN and a private company in order to produce radio-isotopes for medical diagnosis and therapy; δ-phase - neutron beam production by interaction of protons with heavy and light targets for either continuum spectra production (SEE: Single Event

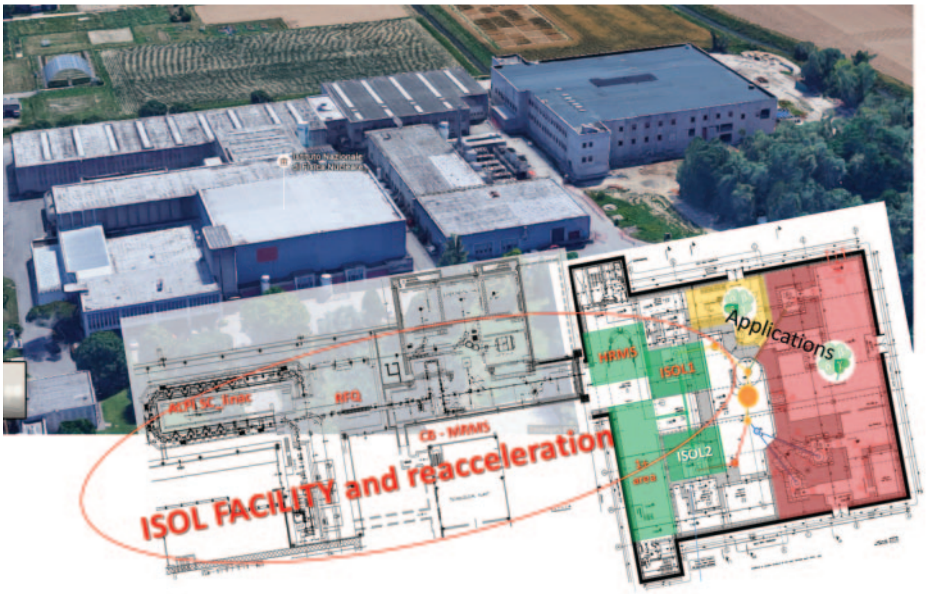

Fig. 1. – Upper part: view of the new SPES building (on the right) and of the TANDEM-ALPI complex (on the left). Lower part: layout of the SPES facility.

Effect study) or quasi mono-energetic spectra: applications of the neutron source range from nuclear astrophysics to test of electronics in space and characterization of nuclear waste.

2. – The SPES β-project

The main part of the project is related to the production of a Radioactive Ion Beam (RIB) facility and, in particular, an ISOL facility devoted to the production of neutron-rich element by means of fission induced by protons on uranium: an intense proton beam ($200\,\mu$A) is directly sent onto a sliced UCx target, with the final aim to produce up to 10^{13} fiss/s [2]. The proton driver is a B70 cyclotron, produced by the BEST company [3] and can deliver two beams simultaneously, at the moment with the same energy but with the possibility of modulating different intensities at the two ports. The B70 cyclotron have been installed and commissioned and it is ready to operate as is shown in fig. 2. A training period for the personnel has been performed and will continue in the forthcoming period. The machine has demonstrated to be stable and reliable and a proton beam of 70 MeV with a current up to $500\,\mu$A has been sent onto a high power beam dump (35 kW).

The core of the project is the Target-Ion Source (TIS) system [4], which is designed to substain up to 8 kW of power on the target. The TIS is integrated in the Front End, a peculiar part of the SPES accelerator which is installed inside the production bunker. The offline FE actually under test is shown in fig. 3. It couples the cyclotron to the TIS itself proton entrance channel and, downstream, it consists of a first selection

Fig. 2. – Views from the SPES building area where the B70 BEST cyclotron is installed. In the lower picture the beam line towards the RIB production is in the foreground.

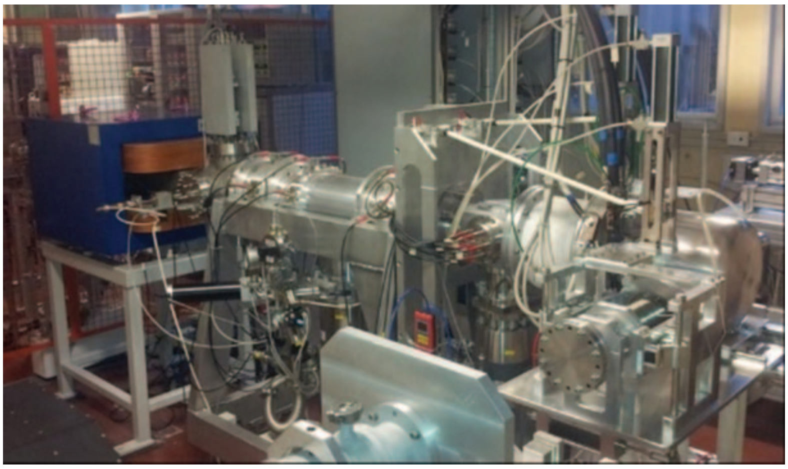

Fig. 3. – Picture of the offline Front End of SPES.

stadium of the produced Radiactive Beams (Wien Filter). The proton beam impinges at 90° degree with respect to the extracted RIB, interacts in the UCx target and finally stops in the last part of the target set-up (Beam Dump), which consists of a series of graphite disks. In order to satisfy different needs, three kind of TIS have been developed: a Surface Ion Source (good efficiency and selectivity for elements like Rb, cs, Ba); a Plasma Ion Source (necessary to ionize elements with high ionization potential, but with very poor selectivity); a Laser Ion Source (which is based on the laser resonant photo-ionization and it is very powerful and highly selective) [5]. The produced RIBs after their extraction by the TIS are directed towards the Wien Filter, which can provide a selection of $\Delta M/M \simeq 1/150$. The major part of the produced radioactivity is kept, so far, inside the bunker itself. Then, outside the bunker, a first series of elements (a Magnetic Dipole plus a series of electrostatic elements) will complete the selection reaching a resolution of $\Delta M/M \simeq 1/200$. All this is called *Low-Resolution Mass Separator system* (LRMS).

Two safety systems (SS) are provided for maintenance operation, able to unlock the target ion-source system from the Front End and to replace it remotely. The main SS is a horizontal Automated Guided Vehicle (AGV) based system, which moves into the bunker, dismount the target and takes it to the temporary storage. A second handling is provided vertically, in case the horizontal system is mulfunctioning: in the roof of the bunker a series of concrete blocks can be removed and a crane-like system can operate and remove the target. A strong study on radiation hard material has been performed in collaboration with the Pavia University and INFN section, since the Front End must operate under a high radiation field inside the bunker: an upgraded version of the FE has been designed, in which many parts have been replaced in order to fullfill the requirements of radiation hardness of materials and sealing.

The layout of the transport line from the production bunker to the low-Energy area (non-reaccelerated RIBs) is shown in fig. 4: after the Wien Filter, which is still installed in the production bunker the beam is selected and sent to a 90° Magnetic Dipole and then transported through a series of electrostatic elements (Triplets, Dipoles) until a Diagnostic Tape Station, designed to characterize the produced beams at the exit of the LRMS. Furthermore, the RIBs may also be transported towards a Beam Cooler necessary to couple the emittance of the beam to the *High-Resolution Mass Spectrometer* (HRMS),

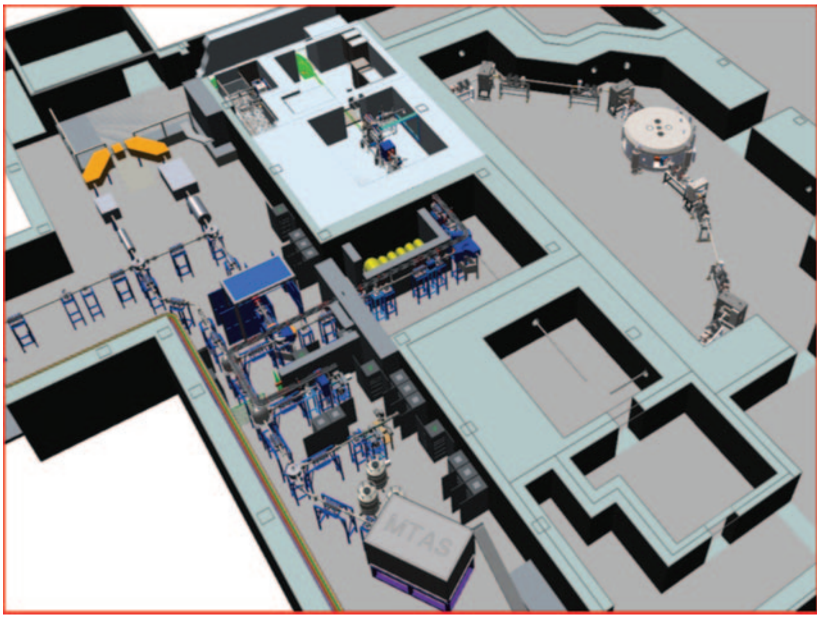

Fig. 4. – Layout of the SPES production area, from the Cyclotron area towards the production bunker, where the Front End is installed and, finally the transport line toward the low-energy 1^+ area for non-reaccelerated beam physics. In the upper left part of the layot the HRMS area is also shown.

which is under design, in order to reach a separation up to $\Delta M/M = 1/20000$.

At the exit of the HRMS the transport line can be splitted: on one side the highly resolved RIB can be sent back to the *Low Energy Area*, on the other side it can be sent towards the post-accelerator. A *Charge Breeding Stage* (CB), necessary to charge up the isotopic species from 1^+ to n^+, is foreseen before the injection in the post accelerator. After the CB a further *Medium Resolution Mass Spectrometer* (MRMS) is used to clean up from possible contaminants generated in the Charge Breeder plasma chamber. In fig. 5 a picture of the Charge Breeder, which is under installation at LNL is shown together with some optical elements of the 1^+ transport line, called ADIGE.

The installation of optical elements, power supplies and of the High Voltage platform of the MRMS has been performed together with the realization of electrical and water cooling plants. In order to couple the 1^+ transport line and therefore to properly inject the RIBS into the ALPI post accelerator, a new normal conductive Resonant Frequency Quadrupole (RFQ), entirely designed at LNL is being constructed: the RFQ injection energy is 5.7 keV/n and the exit energy 727 keV/n. The 24 RFQs electrodes were delivered and the construction of the tanks is progressing.

The ALPI post-accelerator is undergoing a major upgrading: transmission properties, beam intensities and energies will be improved. The main objectives of the ALPI upgrade are: a) the increase the reliability of the accelerator; b) limit the heavy ion beams ($A/Q = 6$–7) losses (maintainability increases with a low contaminated machine); c) increase the energy and the beam current for RIB experiments. The strategy covers also an improved beam instrumentation which should permit the implementation of semi-automatic procedures to allow a better tuning and better reproducibility.

Fig. 5. – The ADIGE Installation phase. Top left: transport line towards the MMRS. Top right: Cabling the Charge Breeder. Bottom: n$^+$ transport line towards the RFQ.

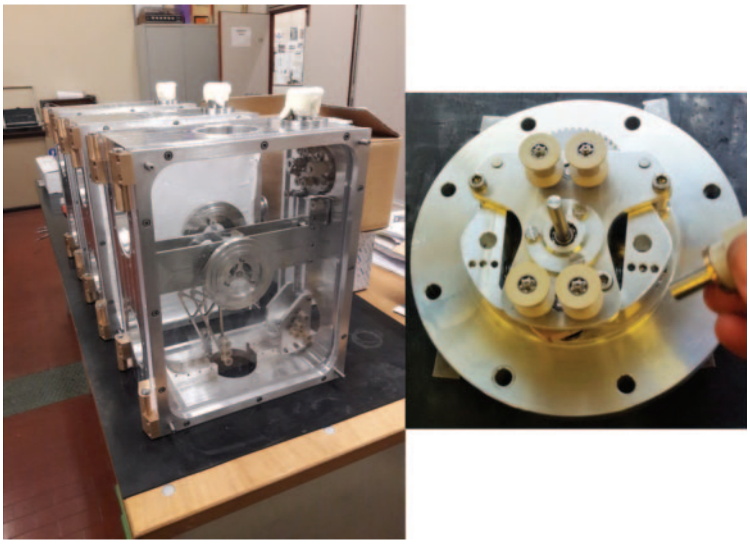

Fig. 6. – Picture of the Tape Station systems in costruction at LNL: two for beam diagnostics and characterization and one for β-decay study. On the right picture a particular of the capstain for the tape rolling.

The SPES performances in terms of beam intensities at the production/extraction point (after the 1^+ ionization) and, for post accelerated RIBs, at the secondary target position (experiment) have been evaluated with MCNPX and reported on the LNL website [6]. Users can download the Beam Tables together with the description of the system from the web page. Moreover, specific tests on the TIS system have been performed and have demonstrated the capability of the sliced SPES target to produce extra yields with respect to the bulk configuration, which was originally used at HRIBF at Oak Ridge National Laboratory (USA) [7].

The SPES scientific program has been discussed in several international meetings, where a *Scientific Advisory Committe* has analyzed the several Letters of Intent which were presented. Up to date instrumental set-ups (PRISMA [8], GARFIELD [9], GALILEO [10] etc.) together with specific ancillary detectors are present at LNL and have been updated to be used with RIBS. Some other apparatus, developed within European Collaborations, will be travelling (like AGATA [11], FAZIA [12] and NEDA [13]) and will come to LNL for specific experimental campaigns. Some more instruments are under development on purpose for the experimental activity at SPES, like for example an Active Target for SPES (ATS) and a β-decay station as shown in fig. 6. In fact, as is shown in the picture two tape stations will be constructed for beam diagnostics and characterization, while a third one for β-decay studies.

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