

THE SPES RIB PRODUCTION COMPLEX

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Abstract

SPES [1] is a second-generation ISOL RIB facility [2] of the National Institute of Nuclear Physics (INFN laboratory, Legnaro, Italy) actually in construction phase. The main goal is to provide intense neutron-rich Radioactive Ion Beams directly impinging a UC_x target with a proton beam of 40 MeV and current up to 0.2 mA. The production target follows an innovative approach which consists in a target configuration able to keep high the number of fissions, up to 10^{13} per second, low power deposition and fast release of the produced isotopes. The exotic isotopes generated in the target are then ionized, mass separated and re-accelerated by the ALPI [3] superconducting LINAC at energies of 10 AMeV and higher, for masses in the region of $A=130$ amu, with an expected rate on the secondary target up to 10^9 particles per second. In this work, we will present the recent results on the R&D activities regarding the SPES RIB production complex (see Fig.1).

THE SPES FACILITY

The radioactive ions will be produced with the ISOL technique using the proton-induced fission of uranium contained in the UC_x [4] direct target and subsequently reaccelerated using the PIAVE-ALPI accelerator complex. The Best C70 cyclotron with a maximum current of 0.8 mA rows two exit ports those will be used as a primary proton beam driver, with variable energy (30-70 MeV). 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 stripping process does the proton extraction, the final energy varies within 35-70 MeV. Two independent extraction channels placed at 180° one with respect to the other, provide the simultaneous delivery of two beams. In order to reach an in-target uranium fission rate of 10^{13} fission/s, a proton beam current of 200 μA (40 MeV) is necessary; the second beam, up to 500 μA and 70 MeV, will be devoted both to neutron production for material research and to research on new isotopes for medical applications. The ISOL technique for radioactive beam production is based on a driver accelerator, which induces nuclear reactions inside a thick target. The reaction

products are extracted from the target by thermal process (diffusion-effusion), ionized, mass separated and injected into a re-accelerator. 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. Before the injection in the ALPI superconducting LINAC it is necessary an increase of the charge state from $1+$ to $n+$. This is performed by means of a ECR Charge Breeder. The linear accelerator ALPI, with a range between about 0.04 and 0.2 and CW operation, represents an ideal re-accelerator for the radioactive beams.

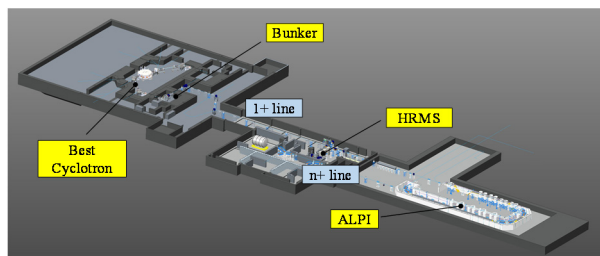


Figure 1: SPES facility. In the image, we can observe the location of cyclotron, production bunker, the path of $1+$ line and $n+$ line toward ALPI, with the HRMS system in the middle.

THE TARGET SOURCE UNIT

In the ISOL facilities, the production target with the ion source constitutes the central component, which are capable to convert the primary beam into a radioactive ion beam. In particular, the reference version of the SPES production target is made of 7 UC_x [5] co-axial disks. These disks have diameter and thickness of 40 and 1 mm, respectively, and are impinged by a 40 MeV 0.2 mA proton beam, thus generating approximately 10^{13} fissions per second. In the SPES project, the primary proton beam is stopped in the target, dissipating its power and generating

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by fission exotic nuclei in the intermediate mass range ($80 < A < 160$). The desired exotic species must be extracted from the target, ionized and accelerated to make the RIB. This process is time demanding and usually unsuitable for atoms having half-lives lower than a few tens of ms.

The main elements produced in the fission process are represented in Figure 2, together with the optimum ionization mechanisms that will be adopted for the production of ion beams from isotopes of these elements.

Figure 2: element table where are put in evidence the elements product with SPES beams.

In the context of the SPES project, two different ion source types will be adopted: the SPES surface ion source (SIS), and the SPES plasma ion source (PIS), shown in Figure 3. The former will be used to produce ions using both the surface and the laser ionization mechanisms, so it is named also as SPES laser ion source (LIS), whereas the latter will ionize the SPES fission fragments according to the electron impact ionization mechanism.

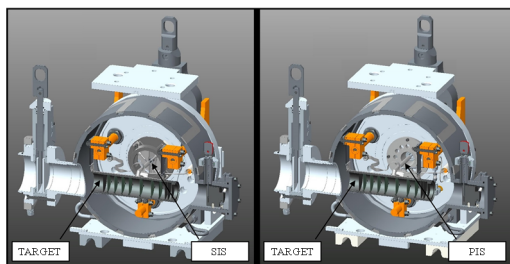


Figure 3: The two ion sources used in SPES project assembled with the target in the vacuum chamber:

- The SIS is the surface ion source;
- The PIS is the plasma ion source.

The target chamber unit, made in aluminium, has a water-cooled base plate and is covered by another water-cooled bell jar. The chamber unit, about 40 kg weight, is coupled to the proton and to the RIB beam lines, by means quick connectors. Two valves isolate the system respectively from the proton beam pipe and from the RIB pipeline. A drawing of the target-ion source chamber is shown in Figure 4.

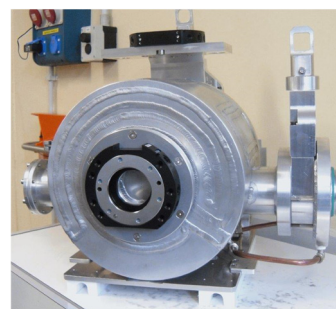


Figure 4: The SPES Target Unit.

THE TARGET MATERIAL

The properties required for the SPES target material, like in the case of other ISOL facilities, are directly related to the efficiency of the processes undergoing between the isotopes production and their release, which can be divided into two distinct phases [5]:

- The diffusion of the isotopes, generated inside the ceramic material grains, towards their surface. This mechanism is governed by Fick's laws.
- The effusion in high vacuum, either in the material pores or in the free spaces surrounding the target discs, towards the ion source.

The obtainment of a fast release of isotopes depends on a large number of parameters, both relative to the material properties and to the target operative conditions. The characteristics required for a material to work with a high efficiency as an ISOL target can be summarized as [5]:

- A sufficiently high cross section for the reaction between the target constituting atoms and the primary beam is required, in order to have a high probability of interaction.
- In order to speed up the aforementioned diffusion and effusion mechanisms, the target material must be able to work at high temperatures (more than 2000 °C) in high vacuum without degradation of its thermo-mechanical properties.
- The material should exhibit high thermal emissivity and conductivity in order to dissipate the power generated by its interaction with the primary beam without undergoing structural damage.
- The target should be highly permeable to exotic species during their path towards the ion source.

The research on materials for the SPES target, as in the case of other existing or future ISOL facilities, represents an important part of the entire facility development.

In recent years [4], the synthesis and characterization of uranium carbide thin discs (SPES target prototypes) have been successfully carried out, and the production methodology can be considered ready to be used to produce real UC_x targets when SPES will be operative.

The synthesis is based on the reaction between a proper uranium source, typically uranium dioxide, and graphite:



which is made to occur at high temperature (up to 1800 °C) in high vacuum ($\sim 10^{-6}$ mbar).

The production route of discs to be used as SPES targets consists of the following steps (the target during production phase is shown in Figure 5):

- Mixing of the precursors powders by means of an agate mortar or using a planetary ball mill. A small quantity of a phenolic resin binder, usually 2% wt., is used to provide a sufficient mechanical stability to be handled without damage and loss of powder.
- Uniaxial cold pressing of the mixed powders into pellets, making use of a hydraulic press and a specifically designed die. In the case of target prototypes, 13 mm diameter dies are commonly used.
- After extraction of the pressed pellet from the die, its thermal treatment is carried out in a high vacuum furnace specifically developed to reach very high temperatures (~ 2000 °C) as described in [5].



Figure 5: Making of the target unit.

THE TARGET REMOTE HANDLING

The target handling system consists of two independent apparatus, called vertical and horizontal devices that will move the target chamber to and from the bunker zone. The horizontal system will be the primary handling device while the vertical one is intended only as a backup solution.

The vertical handling device will access the bunker through a hole on the bunker roof. It will grab the target chamber using an interface tool placed on top of the chamber. On the other hand, the horizontal handling device will access the bunker using a door. In this case, the interface tool is located on the rear of the chamber. Both devices will place and grab the chamber on a coupling table where a series of electro-pneumatic actuators will couple and uncouple the target chamber to the beam lines and open and close the vacuum sectioning valves.

The horizontal system is made up of an Automatic Guide Vehicle (AGV) (see Fig. 6) that will move the target chamber to and from the bunker area and a Cartesian handling system, located on the top of the AGV, that will move the target chamber to and from the coupling table once the vehicle is in position. The AGV can travel following a impose path with reduced tolerances. One optical system will be the primary automatic guide system with a redundancy one to be defined (a possible solution will be chosen among magnetic line driving and laser distance driving). Moreover, manual operation of the AGV from an operator using a joystick and webcams installed onboard will be available.

The Cartesian system is implemented using screw type system and electrical motors.

A PLC on the AGV will control the operations and it will communicate with a user interface. The whole system will be operated on batteries and it works in a completely wireless way.

This kind of solution, even if more cost expensive rather than a fixed rail one, allows more flexibility and a complete isolation of the bunker when all the doors will be closed, due to the absence of holes for the rail.



Figure 6: horizontal handling device made up of the AGV, the Cartesian system and the PLC control.

CONCLUSION

The SPES facility is the main Nuclear Physics project in Italy for the next years. It is organized as a wide collaboration among the INFN Divisions, Italian Universities and international laboratories. SPES is an up to date project in the field of Nuclear Physics and in particular in the field of RIBs, with a very competitive know how, above all in the RIB production system. The SPES RIB complex will represent also an important step in the direction of the European project EURISOL.

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