THE SPES PROJECT: RESEARCH AND DEVELOPMENT FOR THE MULTI-FOIL DIRECT TARGET

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Abstract

SPES is a facility to be built at National Institute of Nuclear Physics (INFN-LNL, Legnaro, Italy) intended to provide intense neutron-rich Radioactive Ion Beams (RIBs) [1] directly hitting a UCx target with a proton beam of 40 MeV and 0.2 mA; RIBs will be produced according to the ISOL technique and the new idea that characterize the SPES project is the design of the production target: we propose a target configuration capable to keep the number of fissions high, the power deposition low and the release of the produced isotopes fast. In this work we will present the recent results on the R&D activities regarding the multi-foil direct UCx target.

INTRODUCTION

The SPES project is focused on the production of neutron-rich radioactive nuclei by ISOL technique, employing the proton induced fission on a direct target of UCx; the fission rate expected with a proton beam of 40 MeV and 0.2 mA is 10^{13} fissions/s. The main goal of the SPES facility [1] is to provide an accelerator system to perform forefront research in nuclear physics by studying nuclei far from stability, in particular neutron-rich radioactive nuclei with masses in the range of 80–160. The final RIB energy on the experimental target will be up to 11 MeV for A = 130, with an intensity in the range 10^7–10^9 pps, depending on the extracted ion species. The bombarding energy achieved allows to overcome the Coulomb barrier in most systems and opens up new possibilities for experimental studies of neutron-rich nuclei, employing different reaction mechanisms such as Coulomb excitation, inelastic scattering, single and multiple nucleon transfer, fusion reactions, etc.

In an ISOL facility the working core is constituted by the production target and the ion source [2]: they have to be designed and optimized carefully in order to obtain the desired RIB production rate (see Fig. 1). In the SPES project, the RIBs extracted from the ion source (coupled to the production target by means of the transfer line) will go through a first stage of A/Z purification, which allows to trap the largest amount of radioactive contaminant.

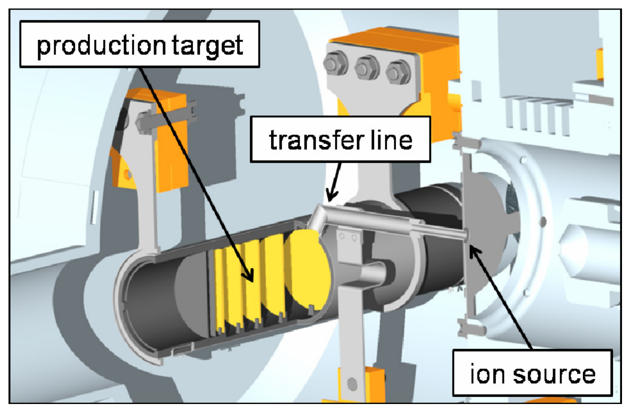

Figure 1: The SPES production target and the ion source.

A small Wien filter will be placed in the platform just beyond the source; it will be followed by a 1/20000 isobar mass separator. To optimize the reacceleration, a charge breeder will be developed to increase the charge state to N+ before the injection of the exotic beam in the PIAVE Superconducting RFQ, which represents the first re-acceleration stage; the second and final reacceleration step will take place in the ALPI superconducting linear accelerator: as reported above, the final RIBs energy on experiments will be up to 11 MeV.

THE TARGET SYSTEM

In the production target - ion source complex for ISOL based facilities, many physical phenomena occur: power deposition, fission, atomic diffusion-effusion, ionization, extraction. In the SPES project, the primary proton beam is stopped in the target, dissipating its power and generating by fission exotic nuclei in the intermediate mass range (80< A< 160) [1]. The desired exotic species must be extracted from the target, ionized and accelerated to make a RIB. This process is time demanding and usually unsuitable for atoms having half lives lower than a few tens of ms. Dealing with a target - ion source system, the intensity of the radioactive beam available at the source output, is usually described by the following equation:

$$I = \sigma \cdot \Phi \cdot N \cdot \varepsilon_1 \cdot \varepsilon_2 \cdot \varepsilon_3 \quad (1)$$

where σ stands for the production cross section, Φ the proton beam intensity, N the target thickness, ε_1 the release efficiency from the target up to the source, ε_2 the ion source efficiency and ε_3 the delay transfer efficiency due to the radioactive decay losses. The SPES target design has been optimized in order to maximize the release efficiency and to exploit, at the same time, devices (basically the ion sources) developed in other laboratories (mainly at CERN, Switzerland). The energy deposited in the target material by the electromagnetic and nuclear interactions has to be removed, and because of the low pressure of the environment, the target can be only cooled by thermal radiation towards the container box surrounding it. In order to optimize the heat dissipation along with the fission fragments evaporation, the SPES target consists of multiple thin disks housed in a cylindrical graphite box [1]. In this way the cooling of the target is strongly simplified: in fact, due to the vacuum environment, the heat dissipation is fully entrusted to thermal radiation: radiative heat transfer is directly proportional to the body surface and in our case the use of 7 thin UCx disks, 40 mm in diameter and 1.3 mm thick each, increases the total surface and allows for a better cooling. It is fundamental to underline that the radiative cooling is supported also by the high temperature level of the target during the working conditions, approximately equal to 2000°C. In this configuration only the protons with higher fission cross-section are exploited in the UCx target discs, while the outgoing lower energy, less than about 15 MeV, is driven towards a passive graphite dump; as a consequence, the power deposited in the UCx is lowered considerably and at the same time the number of fission reactions is maintained high. In the selection of the beam profile, a uniform distribution of the beam has been chosen in order to flatten the power deposition inside the disks as much as possible and consequently to reduce temperature gradients and thermal stresses.

The architecture proposed for the SPES target represents an innovative solution in terms of capability to sustain the primary beam power; the design is carefully oriented to cool the target by thermal radiation, taking advantage of the high operating temperature. The thermal analyses performed [1] show the capability of thermal radiation to cool the disks with a reasonable margin below the material limiting temperature. The release from the target has been carefully studied by means of dedicated computational codes: simulations show that the SPES multi-foil direct target presents a good isotope extraction behavior up to intermediate masses.

The ideal target material for RIBs production should combine different properties which sometimes cannot be fully maximized in a single material: low density, good release properties, good mechanical stability, high thermal conductivity and emissivity, and limited ageing at high temperature under intense irradiation. Such materials must operate for extended periods of time with constant performance and efficiently dissipate the incoming beam power.

The preparation of the SPES UCx disks is based on the carbon-thermal reduction of UO_2 powders in excess of graphite. The powders are mixed and grinded in order to obtain a homogeneous mixture (2 wt.% of phenolic resin is added as binder); these powders are uniaxially cold pressed at 75 MPa for 1 h. Finally the heat treatment is performed in a dedicated vacuum furnace, built at LNL-INFN. The bulk density of the disks turns out to be about 3 g/cm^3, while the atomic ratio of the uranium compared to the carbon is assumed to be U:C=1:4. In Fig. 2 a picture of the first 13 mm UCx pellet is reported.

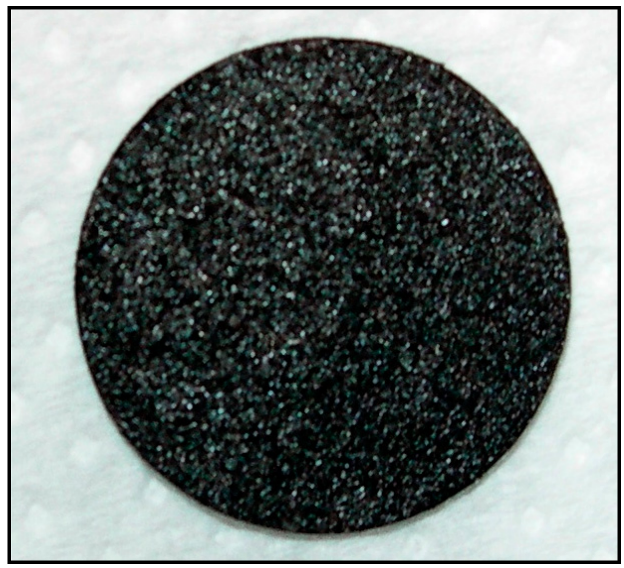

Figure 2: The first UCx pellet for the SPES project.

THE ION SOURCE SYSTEM

The hot-cavity ion source chosen for the SPES project was designed at CERN (ISOLDE) [3]. 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 equal to 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. Ideally that atoms should be ionized +1, then extracted and accelerated to 60 keV and after that injected into the transport system. For alkalis and some rare earth elements high ionization efficiencies can be achieved using the surface ionization technique. For most part of the others elements, the laser resonant photo-ionization, using the same hot cavity cell, is the powerful method to achieve a sufficient selective exotic beams. This technique will be implemented in collaboration with the INFN section of Pavia. The aim is to produce a beam as pure as possible (chemical selectivity) also for metal isotopes, as shown in Fig. 3.

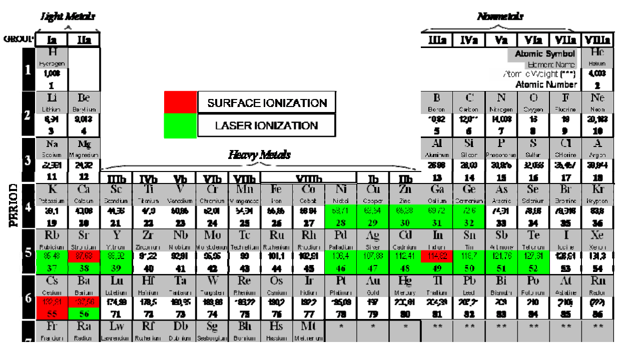

Figure 3: The main isotopes that will be ionized and extracted in the SPES project.

The laser ion source has been investigated in the past at Pavia University, as a spin-off of the atomic vapor laser isotope separation. As first step for the R&D of the photo-ionization process for SPES, dye laser will be used to generate resonant light source. These lasers are in turn pumped by the second harmonic of Nd-Yag laser. All these devices are already present in the Pavia laboratory. The main work in the last months has been to bring back into use either the Nd-Yag, a Quanta System model, and a dye laser, manufactured by Lambda Physik. The spectral characterization of the laser beam is underway. The final goal is the set-up a system composed of three tunable lasers, an atomic beam and a time of flight mass spectrometer. This system is intended for a full diagnostic of LIS applied to the chemical elements belonging to the fission fragments selected by the SPES group.

THE SPES TARGET PROTOTYPE

Recently a full scale target prototype, based on a series of SiC thin disks, was developed and tested off-line (without the presence of the proton beam) at INFN-LNL (see Fig 4). In this prototype seven SiC disks are contained in a cylindrical graphite box, and closed inside the heating system. The present SPES heating system (see Fig. 4) is composed of a thin Tantalum tube, with an average length of 200 mm, an external diameter and a thickness of 50 and 0.35 mm, respectively; it is welded at its edges to two Tantalum wings; they are directly connected to Copper clamps (see Fig. 4) and thanks to them a 10 kW power supply (I_{MAX} = 1000 A / ΔV_{MAX} = 10 V) is able to provide the electric current necessary to dissipate by Joule Effect the “proton beam – independent” heating power.

A coupled electrical-thermal Finite Element model of the target and its heating system was defined using the FE code ANSYS®; it is able to reproduce the electrical and thermal behavior of the target and its heating system. The model was validated by temperature and potential difference measurements; it will be used to optimize the target in a virtual environment, with a great profit in terms of time and money.

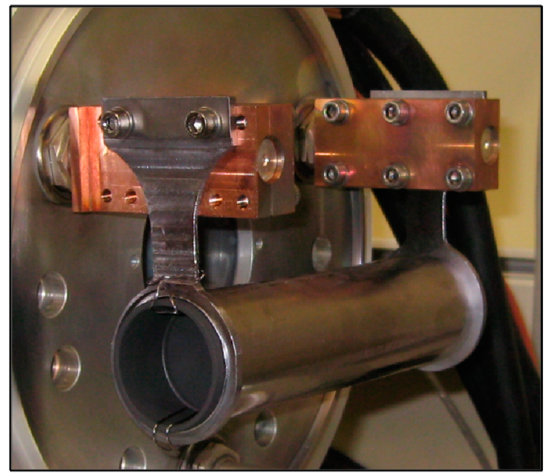

Figure 4: The SPES target prototype.

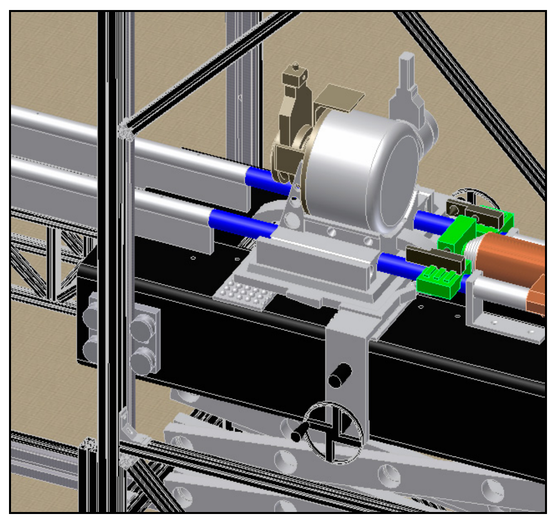

Figure 5: The target chamber handling.

THE TARGET CHAMBER HANDLING

Another important aspect of the R&D for the SPES project is the remote handling of the target vacuum chamber. The chamber used to contain the SPES target and the ion source in vacuum is designed for easy connection and removal from the beam extraction and transport system; it is coupled to the RIB line and to the proton beam channel by means of two quick connectors and two pumping ports which can be sealed off with high vacuum valves moved by pneumatic actuators. Standard industrial components were used to design the chamber handling system, in order to have high reliability, rapid maintenance and limited costs. An image of the designed handling system is reported in Fig. 5.

CONCLUSIONS

The SPES project is one of the main Nuclear Physics development 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 and representing an important step in the direction of the European project EURISOL.

Before starting the construction, the R&D program will continue mainly focusing in the target and in the ion source development and optimization.

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