THE PRIMARY DRIVER

The LNS Superconducting Cyclotron is the primary accelerator of EXCYT. It is a three sectors compact machine with a typical extraction efficiency of 30-50%. The high intensity operations have been made possible by some modifications of the electrostatic deflectors and beam diagnostics.

The first modification was the installation of a cooling circuit on the first electrostatic deflector, Figure 2, assembled in the rear part of the housing , which provided indirect cooling of the septum, the ground element where a big part of the accelerated beam is lost.

Figure 2: Water cooling circuit assembled in the rear part of the deflector housing.

At the same time, it was necessary to upgrade also the main probe, so as to have a diagnostic device able to measure intense beams. The original probe, designed for not intense beams, was replaced by a water cooled one.

With this equipment, it was possible to extract a $^{13}C^{4+}$ 45 AMeV beam with a power of 100 watt.

To go beyond 100 watt, it was decided to introduce further modifications to the electrostatic deflector in order to improve its reliability: a new housing was realized with a new cooling circuit, allowing the septum to be directly cooled, as shown in Figure 3. Moreover the septum material was changed from tantalum to tungsten, which ensures a better thermal exchange. Finally, the septum thickness was increased from 0.15 to 0.3 mm, which ensures a better mechanical stability under thermal stresses. With these modifications, an extraction efficiency of 63% was obtained and a 150 watt beam was extracted in a quite reliable way.

Figure 3: New deflector provided with direct cooling of the septum.

In order to reach the objective set by EXCYT, namely a beam power of 500 watt, it is wise to search for an increased extraction efficiency. This could be achieved by improving the beam formation at the source exit and realizing a better matching between the source and the cyclotron. The immediate result would be an increased injection efficiency, allowing for the possibility of cutting particles out of the machine acceptance. Beam tests will soon be accomplished to study the problem.

STATUS OF THE EXCYT FACILITY

The production yield of the radioactive nuclear beam (RNB) depends on many factors such as: primary beam parameters (element, energy, intensity), target material (nuclear cross-section, operating temperature), target structure (diffusion mechanism), container geometry (effusion to the ionizer), ionizer type (ionization mechanism and efficiency), charge exchange efficiency, transport efficiency, isobaric separation and post-acceleration efficiency.

Target Ion Source Complex

The graphite made target is enclosed in a Ta container and heated by a surrounding electrical heater. The recoils produced in the target will effuse through the transfer tube to the ionizer, where they are ionized by an ISOLDE-type ion source and then extracted by an acceleration voltage up to 50 kV. The sources available for the TIS are the Hot Plasma Ion Source (HPIS), which is suitable to ionize positively many elements, included noble gases with an efficiency of about 1%, and the surface ionization type sources for positive and negative ion production. The positive (PIS) is particularly suitable for alkaline ions for which it is highly selective and efficient, while the negative (NIS) is indicated for halogens with exception of fluorine. The source presently used is the PIS (efficiency measurements indicate a ionization rate around 70% for Lithium beam) [2].

The selection of our target material has been done following the criteria of high porosity, small grain size, high thermal conductivity, high chemical purity, high melting point and low vapour pressure.

Experimental results indicate the UTR146 graphite from XYCarb as the best target material for our facility [3]. Taking into account the Superconducting Cyclotron (CS) operational diagram, the ^{8}Li demand and the target material, we selected $^{13}C^{4+}$, 45 AMeV ion as a primary beam. In this energy range $^{8,9}Li$ are essentially produced both by target and projectile fragmentation: EPAX code simulations indicate the nuclear cross-section for ^{8}Li production to be 3.41 mb and 4.25 mb respectively [4].

The first target prototype used for the preliminary test at SPIRAL in Ganil and at LNS during March 2006 is shown in [5].

It consists of two parts: the upper tablet and the lower part which acts also as mechanical support. The transfer tube to the ionizer is located in between these two parts. Sizes were chosen to maximize the Li collection.

At the operating temperature of 2600°K, many diffusion mechanisms are active inside the target: Li particles will mainly diffuse through interstices in graphite. Once the particle reaches the grain boundary it can diffuse in a neighbour grain or effuse in the target porosity.

Moreover at this temperature, after the effusion process through the porosity, the probability of re-diffusion inside a grain is quite high. For this reason we performed some computer simulations using a very simple, mono-dimensional modified form of Fick's law to reproduce the ^{8}Li production efficiency measured at LNS. It turned out a large value of the diffusion coefficient, thus confirming the good features of this target.

In particular the simulations suggest that only the ^{8}Li particles produced within the first hundreds of microns are able to reach the target surface before their decay, ^{8}Li atoms produced deeper will decay during their path inside the target and will never be collected.

These considerations led the decision to modify the target design by employing ten, uniformly spaced, 1 mm thick, graphite disks (see figure 4). An increase of a factor 6 on the ^{8}Li production yield was then expected.

An increment of a factor 3.6 has been found, which is not far from the foreseen factor 6, this reduction being probably due to a different temperature distribution in the new target design. These values are very promising for the future when the beam power will be increased up to 500 W. Further investigations are planned to better understand the Li release mechanism from the target. Other target candidate materials such as fibres, felts and nano-structured materials are taken into consideration.

Charge Exchange Cell

The charge exchange cell (CEC) is a vacuum chamber containing cesium vapours at a variable temperature, in which Li+ ions, extracted from the ion source, are transformed into negative ones by interaction with the Cesium atoms.

The CEC device and the efficiency measurement procedure have already been described [6]. The charge exchange consists of a two step process, the first of which is energetically supported (exothermic) while the second is not (endothermic). Cesium was chosen because of its low ionization energy. Other alkaline elements exhibit bigger values reducing the CEC efficiency. The CEC efficiency strongly depends on the energy of the Li+ extracted from the TIS: the lower the Li energy the higher the CEC efficiency. The maximum efficiency in this case lies at about 5 keV [6].

The beam optics elements have been originally designed to operate at a typical extraction energy of 15-20 keV. Strong efforts were dedicated to improve the beam transmission at the lowest suitable RNB extraction energy. This value was fixed at 8-10 keV as a good compromise between a good transmission and CEC efficiency. On-line measurements confirm the expectations: the CEC efficiency for ^{8}Li at 10 keV is 3.4%, very close to the expected value of 3.6%.

Figure 4: New target geometry.

Diagnostics

The facility is equipped with beam diagnostics, allowing to acquire in real time all necessary beam parameters (the beam position, the shape and the intensity) for the tuning, and also to identify the transported radionuclides. Along the beam pipe before the Tandem, we have installed the LEBI (Low Energy Beam Imager/Identifier) devices, that allow to visualize the 2D profile of radioactive and stable beams, to measure the beam intensity and to perform the nuclear identification. The sensitivity is high enough, in order to work with very low intensity beams (down to 10^{3} pps). The high sensitivity scintillating screen for the beam monitoring is made of Cesium Iodide doped with tallium, CsI(Tl). Such a screen is covered for a half of its surface, by a very thin (6 μm) aluminized mylar tape, that can be wound in front of it. In case of stable beam monitoring, the beam hits the screen directly, while the radioactive beam hits the tape, in order to avoid the contamination of the screen. In such a case the light spot is produced by the radioactive decay of the radionuclides implanted inside the tape. In order to measure the beam intensity and to perform the identification, LEBI also lodges a plastic scintillator BC408 coupled with a photomultiplier (Hamamatsu R1924A), in order to detect the beta particles emitted by the radionuclides decay. The detection efficiency has been calculated by the Montecarlo code Penelope, and for the ^{8}Li nuclei is 0.45. A couple of germanium detectors positioned at a relative angle of 90°, can detect gamma rays emitted in the decays, thus allowing a more accurate identification of the particles. In figure 5 two profiles for a stable (left) and unstable ^{8}Li beam (right) are shown.

For the accelerated beams, the diagnostic devices that we have used up to now to measure the beam intensity consist of 3 x 3 cm^{2} silicon detectors.

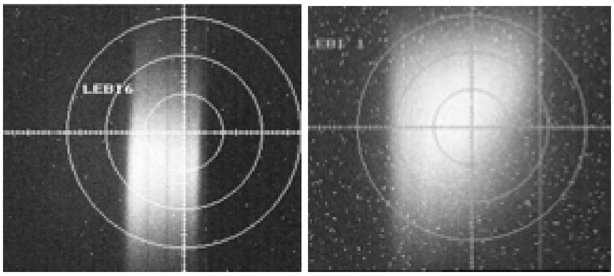

Figure 5: Beam profiles acquired with LEBI for a stable (left) and a radioactive beam (right). The intensities are below 1 pA.

However, such devices are not suitable to work over 10^4 pps, because of radiation damage, therefore we have decided to install plastic scintillators BC408 coupled with pmt for such purpose. A position sensitive (PSD) silicon detector (50 x 50 mm^2) has been adopted as a beam profile monitor. This is able to reconstruct the impact position of each particle, by reading the signals produced at the four vertex of the detector. In the telescope configuration, it also allows to identify the Z and A of each particle. In figure 6, the reconstructed coordinates of alpha and beam particles crossing a mask with several holes, are shown.

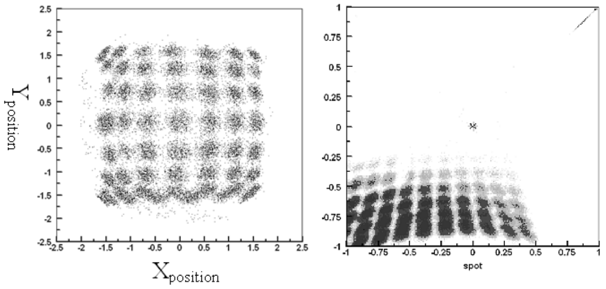

Figure 6: Mask profiles acquired with alpha particles (left) and ^{8}Li beam (right), using the silicon PSD. The scale axes are different.

In order to manage all the installed devices (10 LEBI's, 15 PMT and 15 PSD) a suitable software platform based on LAB VIEW have been designed. An easy user interface allows the operators to control the main functions of the devices and to acquire all the data useful for the beam transport.

PRESENT CAPABILITIES AND PROSPECTS OF THE EXCYT FACILITY

With the successful production and post-acceleration of ^{8}Li, the commissioning of the EXCYT facility has been completed and the beam delivered to the first experiments approved by the LNS Scientific Committee. The RNB production is sufficient to deliver to the users a good beam quality in terms of stability, purity and intensity for the experimental program already approved by the LNS PAC. This is an important achievement, considering that the facility is installed in the accelerator area, most of the time not accessible during the routine operation of the LNS accelerators with stable beams.

Using a primary beam of 100 watt, $5.4 \cdot 10^6$ pps of ^{8}Li+ are produced. After the CEC, $1.5 \cdot 10^5$ pps of ^{8}Li- are transported through the mass separator until the Tandem entrance. The transport efficiency through the two stages of the isobaric mass separation is close to 100% as expected. The acceleration transmission at the Tandem is of the order of 50%, lower than with Li stable beams, therefore some improvements are planned in the injection line of the Tandem, possibly the installation of a new quadruplet. The final intensity of ^{8}Li on target is $5 \cdot 10^4$ pps.

Further improvements are needed to make the facility more reliable and performing. Different activities are under way to achieve this goal: a factor three is requested to the Superconducting Cyclotron and a lot of efforts are focused on the optimisation of the TIS assembly. Actually the CEC efficiency is the major bottleneck to overcome. The TIS extraction voltage reduction has given a successful improvement on the RNB yield, however several alternative solutions are taken into account to directly produce negative Li ions.

This overall optimisation process involves several key points of the facility (CS, TIS, CEC, Tandem), but it will permit a significant increase of the beam intensity on target. In particular a ^{8}Li intensity up to $5 \cdot 10^5$ pps can be expected at the experimental point in the future.

Finally, the installation of a different source type is planned in the near future: the aim is to start developing a new radioactive beam, different from ^{8}Li, that can be of scientific interest for users. A possible choice might be ^{15}O.

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