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The SPES project at the INFN-Laboratori Nazionali di Legnaro

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Summary. — The SPES Radioactive Ion Beam (RIB) facility is in the construction phase at INFN-LNL. It is based on a dual exit high current Cyclotron, with tunable proton beam energy 35–70 MeV and 0.2–0.5 mA, used as proton driver to supply an ISOL system with an UCx Direct Target able to sustain a power of 10 kW. The second exit will be used for applied physics: radioisotope production for medicine and neutrons for material study. The ISOL system will produce neutron-rich radioactive ions by proton induced fission in the UCx target. The expected fission rate in the target is in the order of 10^{13} fissions per second. The exotic isotopes will be re-accelerated by the ALPI superconducting LINAC at energies of 10 AMeV and higher, for masses around $A = 130$ amu, with an expected beam intensity around 10^7–10^9 pps. Fast neutron spectra will be produced by the proton beam interaction with a conversion target. A production rate in excess of 10^{14} n/s is expected. The SPES project has the aim to provide high intensity and high-quality beams of neutron-rich nuclei as well as to develop an interdisciplinary research center based on the cyclotron proton beam. The status of the project will be presented.

PACS `29.20.dg` – Cyclotrons.
PACS `29.27.-a` – Beams in particle accelerators.
PACS `21.10.-k` – Properties of nuclei; nuclear energy levels.
PACS `29.25.Dz` – Neutron sources.

1. – Introduction

SPES [1] is an INFN project to develop a second generation ISOL (Isotope Separation On Line) facility for reaccelerated exotic beams, mainly neutron-rich ions. The construction of SPES involves the two national laboratories: LNL and LNS and other INFN sites in Italy. The SPES strategy is to develop a nuclear Physics facility able to give an immediate application outcome.

The project is based on a high power cyclotron accelerating H^- able to supply two independent proton beams at the same time ranging from 35 to 70 MeV and a total current of 750 μA. The cyclotron supplies an ISOL target, an application facility for the production of radioisotopes of medical interest and a neutron converter target for the production of high energy neutron beams. The SPES facility is under construction at the Legnaro National Laboratory (LNL), Italy [1]. The full project is divided into four phases, with separate financial budgets, in order to complete them independently:

- Alpha phase:
  1. construction of the new building;
  2. development and installation of the exotic beam production target and set-ups [2].
- Beta phase: related to the exotic beams transport and post-acceleration performed with the upgraded ALPI [3] Linac post-accelerator.
- Gamma phase: related to medical applications and radioisotope production, the LARAMED project [4].
- Delta phase: this is dealing with a dedicated area for proton and neutron beam irradiation facilities.

The Alpha and Beta phases are completely financed by INFN for a total amount of 50 M€. The LARAMED project is partially financed by MIUR (Italian Ministry of research) and is under construction. The neutron facility is at design study level. Nevertheless the building is designed and constructed to host the full facility.

2. – The SPES layout

The primary proton beam provided by the cyclotron accelerator is sent onto the ISOL target, mainly UCx, designed to sustain a beam power of about 10 kW (40 MeV protons at 250 μA) in order to produce 10^{13} fission/s inside the target. The reaction products are extracted by thermal process due to the high temperature of the target-ion source system (exceeding 2000 °C) and ionized 1+ by Surface Ionization source, plasma source or Selective Resonant Laser source according to the requested beam.

Inside the production bunker a first mass selection is performed with a Wien Filter (1/100 mass resolution). A 90° magnet performs a further mass selection at 1/200 and only one mass is transported toward a Beam Cooler coupled to a High Resolution Mass Separator (1/20000). A 1+ electrostatic beam transport line drives the beam to a Charge Breeder (ECR based, developed by LPSC-Grenoble) [2] which increase the ion charge to n+. After a mass selection to clean the beam from the Charge Breeder contaminants, the exotic beam is pre-accelerated by a RFQ and sent to the ALPI linac for reacceleration to 10–12 MeV/n. The layout of the system is shown in fig. 1. A new building was built to host the cyclotron, with the ISOL bunkers and beam selection on the left side. Three bunkers on the right side are available for radioisotopes studies and production (LARAMED), and an area is dedicated to neutron production.

3. – Status of the construction

The project is at an advanced phase of construction. The building is almost finished, nevertheless the cyclotron area was completed and ready to host the cyclotron. The cyclotron was built by BEST Theratronics and is under installation in the new building. The commissioning of the accelerator started late in September 2015 and is underway. The main characteristics of the cyclotron are reported in table I.

Fig. 1. – Layout of the SPES project.

Table I. – *Cyclotron main parameters.*

Accelerator Type	Cyclotron AVF 4 sectors
Particle	Protons (H^- accelerated)
Energy	Variable within 30–70 MeV
Max Current Accelerated	750 μA (52 kW max beam power)
Available Beams	2 beams at the same energy (upgrade to different energies)
Max Magnetic Field	1.6 tesla
RF frequency	56 MHz, 4th harmonic mode
Ion Source	Multicusp H^- $I = 15$ mA, Axial Injection
Dimensions	$\Phi = 4.5$ m, $h = 1.5$ m
Weight	150 tons

The advantage to operate two beams at the same time results in a total amount of beam on target of more than 10.000 hours divided on four target stations allowing the cooling down of the targets after each irradiation run. 15 days of beam-on and 15 days of beam off at each target is considered. The components of the ISOL system developed and under test are: the ISOL target-ion source and the Charge breeder. The first is installed off-line at LNL and was tested in-beam at high power at iThemba LABS confirming the capability to sustain the power necessary to produce 10^{13} fissions/s in the target. The Charge Breeder was developed by LPSC-Grenoble and is now installed at LNL and undergoing the test phase; The beam transport line has been partially acquired, mainly the n+ beam line from the Charge Breeder to RFQ together with the mass separator following the Charge Breeder. The radiological survey system was also acquired and the Personal Protection System is designed and ready for tendering. The design of the RFQ is completed and the bid for construction will be launched at end 2015.

4. – Applications

LARAMED [4] is the main application project of SPES; with the goal to develop new radioisotopes for medicine taking advantage of the 70 MeV proton beam and the high current supplied by the cyclotron. The high energy allows the production of isotopes as Cu-67 and Sr-82. The interest to produce these isotopes is related to supply research activity in case of Cu-67 and to asses a commercial collaboration with a company for the production of Sr-82. This isotope is of great interest as it is used for the production of the Sr-82/Rb-82 generator. There is a worldwide interest for this generator as it is used for cardiac diagnostic. The LARAMED scientific goal is to develop a joint research laboratory of INFN, CNR, Universities and external companies to perform measurement of cross section through targets activation, design and test of high power targets for radioisotope production and develop a radioisotopes/radiopharmaceuticals production test facility dedicated to non-conventional radioisotopes. LARAMED has been partially funded by Italian Research Ministry (MIUR) and the infrastructures are under construction. Further funding will come from a collaboration between INFN and a private company.

A second program for medicine at SPES is the ISOLPHARMA project, focused on the use of the ISOL system to produce radioisotopes for medicine at high specific activity and purity. A patent is pending for the production of Sr-89 at specific activity of 600 GBq/mg, to be compared with 0.004 GBq/mg of the conventional method using a reactor. An interdisciplinary collaboration is involved in the project: INFN-LNL, Pharmacy Department of Padua University and Castelfranco Hospital (a radioisotope production site of Veneto Region).

Another application project is NEPIR that makes use of the proton beam of the SPES cyclotron to produce fast neutrons ($E \geq 1$ MeV). The NEPIR project (NEutron and Proton IRradiation facility) [5] is under design with the aim to develop both a multidisciplinary Quasi Mono-energetic Neutron facility (QMN) [6], and a complementary system for studying neutron-induced Single Event Effects (ANEM) [7] in microelectronics.

The QMN will allow the study of energy dependent neutron interaction mechanisms. Many fields can take advantage from such a QMN facility, *e.g.* manufacturers/users of radiation instrumentation and dosimeters (energy response and calibration); radiation protection (shielding-benchmark experiments); high-energy and nuclear physics (cross-section data for basic science, MC code development and nuclear applications).

The QMN will be produced by an assortment of thin Li and Be targets (1–4 mm). The proton energy and thickness of the targets will be changed accordingly to produce nearly mono-energetic neutrons at several discrete energies. The protons that pass through the targets are deflected by a bending magnet and guided to a heavily shielded beam dump. A multi-angle collimator will be used to correct data taken in the forward (0°) direction, by subtracting data obtained at larger angles (typically in the 15–30 range).

Radiation effects in electronics is a very important field of scientific research and radiation tolerance is strategic for the many applications of electronics in science and research: High Energy Physics, Nuclear Reactors, Nuclear Medicine and Space Applications and Avionics. In particular the vital instruments onboard high altitude flights are constantly exposed to neutrons produced in cosmic-ray air showers.

The study of the interaction of fast atmospheric neutrons ($E \geq 1$ MeV) with electronic chips is the main goal of ANEM (Atmospheric NEutron EMulator).

Atmospheric neutrons have energies that exceed 1 GeV while the SPES cyclotron is limited to 70 MeV, nevertheless it is of great interest as the energy range 1–70 MeV covers more than 60% of fast atmospheric neutrons and there is a marked increase in the sensitivity of digital electronic devices to neutrons with energies below 10 MeV, brought on by continued miniaturization.

The ANEM target is able to produce an accurate reproduction of the atmospheric-neutron spectrum up to 70 MeV. It is based on a novel technique: a rotating water-cooled target made of Be and W circular sectors. Protons from the cyclotron alternatively impinge on the two sectors of different areas; the effective neutron spectrum is a weighted combination of the spectra from the two sectors. Heavy materials such as W well reproduce the lower energy part (few MeV) of the atmospheric neutron spectrum; Be provides more high energy neutrons. By adjusting the ratio of the areas of the sectors, the effective neutron spectrum can be shaped to resemble the atmospheric one, up to the cyclotron energy.

With a $7\,\mu$A proton current it is expected a neutron flux $\Phi(1\text{–}70\,\text{MeV}) = 10^7\,\text{n/s/cm}^2$ at 3 m from the target, an acceleration factor respect to the atmospheric spectra of 3×10^9, a very competitive flux for SEE testing.

5. – Conclusions

SPES is a project for the production of reaccelerated exotic beams by ISOL technique. The system is presently under construction at LNL. The building is almost completed. The cyclotron, provided by the BEST company (Canada), is under installation. The commissioning phase is expected to start in September 2015. The cyclotron capability to produce two proton beams at the same time allows the operation of both a nuclear Physics facility and an application facility.

The ISOL system will produce neutron rich beams from proton-induced fission of U-238. The fission rate in the UCx target is 10^{13} fission/s. Expected rate for reaccelerated Sn-132 is 10^7 pps.

The applications are focused on medicine and neutron beams production. The projects LARAMED and ISOLPHARMA are dedicated to the production and study of new radioisotopes for medicine. The neutron facility NEPIR is under design with the aim to produce quasi mono-energetic neutron beams and a SEE facility for single event study in electronics components and systems.

REFERENCES

[1] Prete G. *et al.*, *EPJ WoC*, **66** (2014) 11030.
[2] Lamy T. *et al.*, *Rev. Sci. Instrum.*, **75** (2004) 1624.
[3] Dainelli A. *et al.*, *Nucl. Instrum. Methods A*, **382** (1996) 100.
[4] Esposito J., *The LARAMED project at INFN Legnaro National labs.*, in *EuCheMS 8th International Conferences on Nuclear and Radiochemistry (NRC-8) - Como, Italy 16–21 September 2012*.
[5] Bisello D., Esposito J., Mastinu P. F. *et al.*, *Phys. Proc.*, **60** (2014) 66.
[6] Bisello D., Esposito J., Mastinu P., Prete G., Silvestrin L. and Wyss J., *Phys. Proc.*, **60** (2014) 271.
[7] Acosta Urdaneta G. C., Bisello D., Esposito J. *et al.*, *ANEM: a rotating composite target to produce an atmospheric-like neutron beam at the LNL SPES facility,* to be published in *Int. J. Mod. Phys. Conf. Ser.*, June 2015.