SPES
Selective Production of Exotic Species
Technical Design Report

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Editors
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SPES (Selective Production of Exotic Species) is an INFN project to develop a Radioactive Ion Beam (RIB) facility as an intermediate step toward EURISOL.

The SPES project is part of the INFN Road Map for the Nuclear Physics development in Italy and is supported by the whole Italian Nuclear Physics community and mainly by LNL and LNS the National Laboratories of Legnaro and Sud (Catania). The INFN capability to play a role in this research field is supported by the consolidated know-how in accelerators and detectors construction, the presence at LNL (Laboratori Nazionali di Legnaro) of the superconducting RFQ PIAVE and the superconductive linac ALPI, able to re-accelerate exotic ions at 8\textasciitilde13 MeV/u and the development at LNS (Laboratori Nazionali del Sud) of the EXCYT project, an ISOL RIB facility for light ions.

The site for the facility construction was chosen at LNL due to the presence of the PIAVE-ALPI complex, which will be used as re-accelerator, and the availability of the necessary real estate, thanks to the extension of the Laboratory site (more than a factor two in area respect to actual size). Primary services and new infrastructures, like a 40 MW power station, are currently under implementation at LNL.

It is part of the SPES project a neutron facility for medical, astrophysical and material science applications based on the high current RFQ developed within the TRASCO project, as worked out in the first proposal of the SPES project presented in the report LNL-INFN (REP)181/02-June2002. Here it is outlined a revised form of the project. The major difference respect to the older one is related to the target concept that was changed from a Two Step to a Direct Target without changing the basic goal to have an ISOL facility for neutron-rich beams of fission fragments with a fission rate in the target of 10^{13} fissions per second. The new configuration reduces significantly the complexity of both the target structure and the primary accelerator. To produce a fission rate of 10^{13} fissions per second, the minimum requirements for the driver accelerator is to deliver a proton beam of 40 MeV energy and 0.2 mA current on a target of UCx (production target) made by 7 disks, each of 1 mm thickness and 4 cm diameter. These kinds of requirements for the proton driver accelerator can be met by a commercial cyclotron as well as by the development of a Linac accelerator.

The use of a Linac accelerator guarantees a future upgrade of the proton driver in energy and current and this solution, described in the report INFN-LNL-220(2007) available on the LNL web site, make use of a proton driver divided into two sections: the high current RFQ and the high energy DTL. In this project the RFQ supplies a low energy proton beam of 5MeV with a current of 30 mA CW and the DTL a 50Hz pulsed proton beam at 43 MeV and 0.5 mA upgradeable up to 100MeV, 1mA following the CERN design of LINAC4. It is also discussed the possible splitting of the beam to supply two end users; in this case the two proton beams have a repetition rate of 25Hz and a mean current of 0.25 mA.

The cyclotron solution is affordable, from the technical point of view, by a commercial solution and offers a proton beam which covers the possible upgrade of the RIB production target. The SPES Steering Committee advise this solution to be adopted for SPES and this last version of the project is described in the present report, together with the development of a neutron beam facility based on the high current proton RFQ, that is already in an advanced construction phase. The proposed cyclotron is a H\(^+\) accelerator with 2 exit ports allowing the delivery of two independent CW beams with an energy ranging from 40 to 70 MeV and a total current of 0.75 mA with possible upgrade to 1.5 mA. In this configuration a variety of solutions are possible as two proton targets can be operated at the same time independently of the neutron facility, opening the possibility to study the neutron cross section of exotic species eventually produced with a selected RIB.

The total amount of UCx required in this project for the radioactive beam production is in the order of 30g. The specific power released by the proton beam in the target is 140W/gr, a power density similar to that of HRIBF, the ISOL facility at the Oak Ridge National Laboratory (USA).

INFN gains the expertise to operate an ISOL facility with the EXCYT project at LNS. EXCYT is a direct target ISOL facility for the production of light exotic ions, based on the 500W \(^{13}\)C beam of the CS superconductive cyclotron. It is successfully operating at a primary beam power density of 200-400 W/gr.
on a graphite target. The EXCYT expertise in designing and commissioning an ISOL facility will be a starting point for the SPES project.

The key feature of SPES is to provide high intensity and high-quality beams of neutron rich nuclei to perform forefront research in nuclear structure, reaction dynamics and interdisciplinary fields like medical, and biological sciences.

The exotic isotopes will be reaccelerated by the ALPI superconducting linac at energies of 10AMeV for masses in the region of A=130 amu with an expected rate on target of $10^9$ pps. The possibility to increase the energy sensibly beyond this limit requires a different approach as the lattice of the ALPI laboratory is approaching its limit. A possible upgrade toward exotic beams at Fermi energies can be a second step which may involve the development of SPES, with the construction of a new re-accelerator as well as the development of EXCYT with the installation of a new primary beam driver allowing using the CS as high energy re-accelerator. It is to be stressed that the two options are not alternative but rather complementary, as the two facilities are designed for different regions of radioactive beam masses.

Most of the experiments made with the existing first-generation facilities are limited by the poor beam intensity. A real breakthrough in the field will be possible only with facilities like SPES, producing both one order of magnitude higher beam intensities and much more exotic ion species than presently available. The research goal for SPES is the study of the many-body aspects of the nuclear structure by addressing important questions regarding nuclei far from stability as one gets closer and closer to the neutron drip line. The exotic beams produced by SPES will open 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. Such reactions not only provide invaluable nuclear structure information but they also allow reaching nuclei even further away from the stability line. Beams of neutron-rich nuclei offer better chances to synthesize heavy elements because the fused system will be less neutron deficient, therefore closer to the valley of stability and with better chances to survive.

Additional addressed questions are related to astrophysics and nucleosynthesis in supernovae and other stellar processes and to tests of symmetries. Facilities like SPES will allow learning much more about the origin of the elements in the cosmos and the limits of nuclear stability.

The SPES project is of great interest not only for Nuclear Physics but also for a direct application of nuclear physics techniques in medicine and in material science. As previously pointed out it is part of the project the development of a neutron facility operated by the high intense 5 MeV proton beam which allows the production of neutrons with a rate of $10^{16}$ n/s and fluencies of thermal neutrons of $10^9$ n s$^{-1}$ cm$^{-2}$ using proper converters and moderators. By using the neutron beam, the SPES project will develop a Boron Neutron Capture Therapy facility (BNCT) for cancer treatment with the aim to produce the first facility of this kind based on accelerators instead of reactors and opening the way to the use of BNCT in hospital site.

The neutron beam will be used to study the neutron cross sections actually needed to take advances in several fields like nuclear astrophysics, nuclear waste transmutation, generation IV reactors, fusion reactors, decommissioning of first generation fission reactors, radioprotection, dosimetry and material science.

The proton beam at high energy and quite high intensity can be directly used for the production of new radio isotopes for internal radio immunotherapy, a technique at the frontier of nuclear medicine or to study specific aspects related to the new generation of power reactors.

With the SPES proposal, it is intended to fulfill the INFN-Community expectations: to exploit their expertise and capability in the fields of accelerators, radiation detectors and related technologies; to maintain and extend their substantial community of users; to preserve and increase their internationally recognized reputation in nuclear structure and reaction mechanisms studies; to offer a neutron site for fundamental and applied physics, for applications in astrophysics, condensed matter, radiobiology and radiotherapy and to contribute to the design and test of high intensity proton beam of interest for other INFN communities and Government commitments (ADS, IFMIF).

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