Laboratori Nazionali di Legnaro
INFN-LNL-224 (2008)

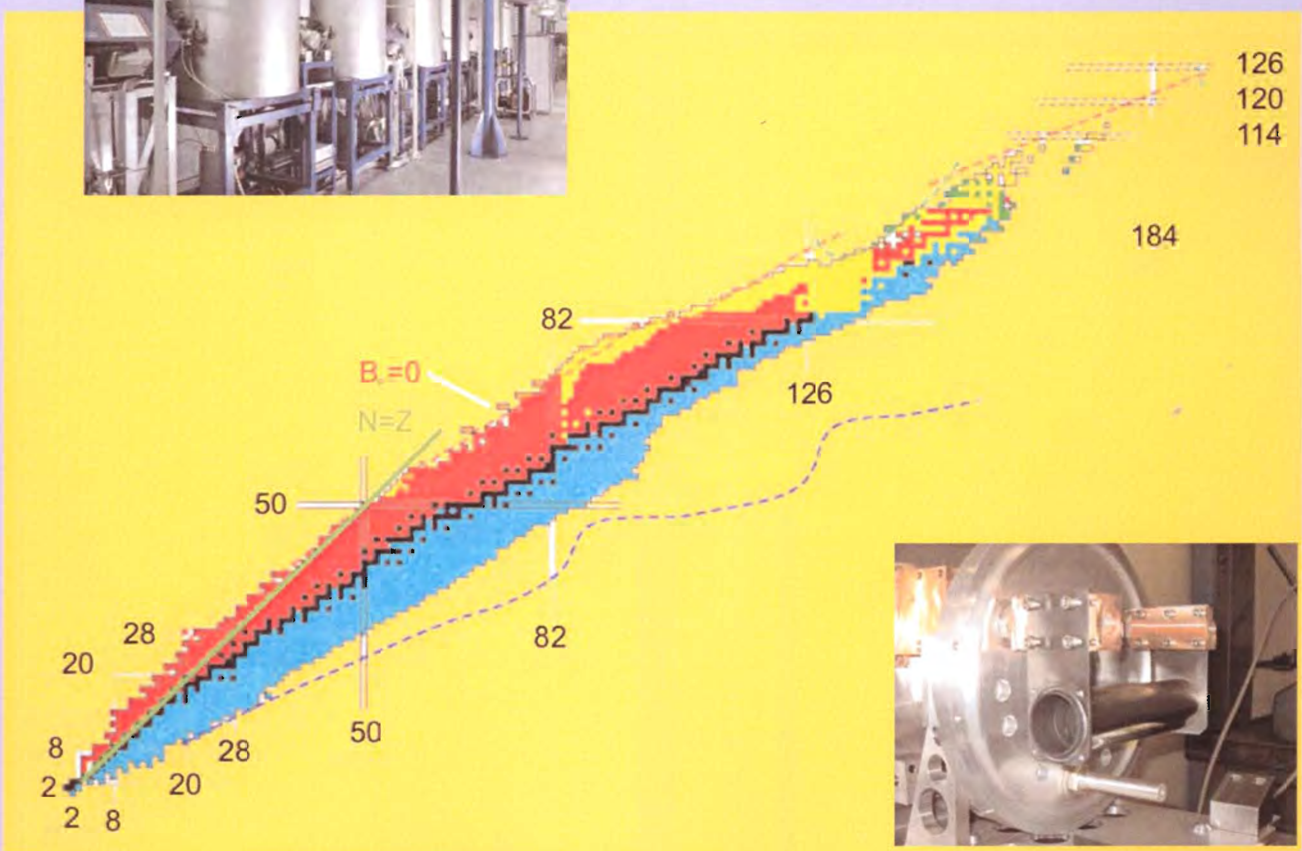
INFN
Istituto Nazionale
di Fisica Nucleare

SPES

Selective Production of Exotic Species

Executive Summary

SPES
exotic beams for science



A.Covello, G.Prete
Editors

SPES PROJECT

EXECUTIVE SUMMARY

Preface

This document presents the Executive Summary of the SPES Project (Selective Production of Exotic Species). An extended Technical Design Report is available on the web site of the Laboratori Nazionali di Legnaro: http://www.lnl.infn.it/~spes

The Executive Summary is intended to give a SPES survey addressing the main components of the project. It provides brief summaries of the accelerator facilities, the scientific programs, civil construction and safety, as well as the work project structure, costs and schedule.

The SPES project is the result of an extended discussion within the INFN Nuclear Physics community; the working group and the authors of the various contributions are listed at the end of this document.

Several proposals were made for the SPES project since 2002, with the aim to fulfil the physics goals and the budget constraints, the main objective being to develop a second generation ISOL facility on the way to EURISOL. Reaccelerated beams of neutron rich nuclei produced by Uranium fission with a fission rate on the order of 10^{13} fission s^{-1} in the production target are expected.

The actual proposal represents an effective cost project, which fulfils the original requirement for the production of neutron rich radioactive ion beams able to make a breakthrough in studying nuclei far from stability, and takes advantage of proton drivers accelerators and selected exotic species to open up the possibility for application of nuclear physics in other fields, as astrophysics, medicine and material science.

The index of the Technical Design Report 2008 (TDR) is reported in the following to give to the reader a hint on the TDR document.

SPES Technical Design Report INFN-LNL-223 (2008)

INDEX

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August 2008

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Foreword

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 (National Laboratories of Legnaro and Sud). 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 of the superconducting RFQ PIAVE and the superconductive linac ALPI, able to re-accelerate exotic ions at 8÷13 MeV/u and the development at LNS 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 with 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 ensuring the necessary electrical power and basic services.

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 original 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 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, biological and material 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. This represent a substantial improvement to the actual available ISOL facilities both from the point of view of intensity and energy of the exotic beam.

The extended and updated Technical Design Report of SPES was prepared in April 2008 and sent to the INFN Board for evaluation of the project.

In this Executive Summary only the essentials of the SPES project and of the physics case are presented.

The Spes facility will open up new frontiers in the study of nuclei far from the line of stability and will allow addressing key science questions . This will place INFN at the forefront of Nuclear Physics Research in Europe well beyond the next decade.

Gabriele Puglierin,
Director of Laboratori Nazionali di Legnaro

Marcello Lattuada,
Director of Laboratori Nazionali del Sud

1. Physics case

Most of our present knowledge of nuclear properties has been gained by studying nuclei near the valley of beta stability or on the neutron-deficient side with respect to the two variables: excitation energy and spin. Very asymmetric combinations of protons and neutrons are expected to reveal new aspects of nuclear structure and reaction dynamics under extreme conditions of isospin. This new physics will be briefly discussed in the following as a motivation for the construction of a facility devoted to acceleration of and experiments with neutron-rich radioactive nuclei.

The main goal of the proposed facility is to provide an accelerator system to perform forefront research in nuclear physics by studying nuclei far from stability. The SPES project is concentrating on the production of neutron-rich radioactive nuclei with mass in the range 80-160. This is a vast territory that has been little explored, if one excludes some decay and in-beam spectroscopy following fission.

The final energy of the radioactive beams on target will range from few MeV/u up to 11 MeV/u for A=130. This energy allows to overcome the Coulomb repulsion between the radioactive beam and the target nuclei 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. Such reactions allow to reach nuclei far away from the stability line, thus providing very valuable information on nuclear structure and dynamics. Beams of neutron-rich nuclei offer also 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.

In addition to pure nuclear physics aspects, radioactive ion beams will have a number of applications at very low energies (fundamental tests of symmetries in decay spectroscopy using traps to confine exotic ions) and at low energies (reactions of astrophysical interest performed in inverse kinematics). The availability of intense neutron fluxes will allow specific programs in interdisciplinary fields as cancer therapy and material sciences as well as astrophysics with the study of neutron capture cross sections.

At the highest bombarding energies, beams of neutron-rich nuclei will allow to extend the knowledge of the nuclear equation of state (NEOS) in asymmetric systems and to explore the limiting temperature regime. Let us now summarize the physics case of SPES.

Starting from a nucleus on the stability line and adding successively neutrons one observes that the binding energy of the last neutron decreases steadily until it vanishes and the nucleus decays by neutron emission. The position in the nuclear chart where this happens defines the neutron drip line. It lies much farther away from the valley of stability than the corresponding drip line associated with protons, owing the absence of electrical repulsion between neutrons. The location of the neutron drip line is known only for nuclei with mass up to around 30.

The interest in the study of nuclei with large neutron excess is not only focused on the location of the drip line but also on the investigation of the density dependence of the effective interaction between the nucleons for exotic N/Z ratios. In fact, changes of the nuclear density and size in nuclei with increasing N/Z ratios are expected to lead to different nuclear symmetries and new excitation modes. While in the case of some very light nuclei a halo structure has been identified, for heavier nuclei the formation of a neutron skin has been predicted.

The evolution of nuclear properties towards the neutron drip line depends on how the shell structure changes as a function of neutron excess. This evolution has consequences on the ground state properties (spin, parity, and electromagnetic moments) and on the single-particle and collective excitations. In particular, studies of neutron-rich nuclei beyond doubly magic ^{132}Sn are of key importance to investigate the single-particle structure above the N=82 shell closure and find out how the effective interaction between valence nucleons behaves far from stability.

A powerful tool to study the evolution of shell closures far from stability is provided by fusion and transfer reactions. For instance, one-particle transfer reactions allow one not only to determine the position of the single-particle states (providing information on the effective mass), but also their occupation probabilities via the spectroscopic factors, which provide detailed information on the mixing of single particle states with more complex configurations.

The location of even a few lowest-lying excited states may provide crucial information on the dynamics of nucleons in the nuclear medium. This is particularly so when looking for evidence of the occurrence of dynamic symmetries in nuclei far from stability, as the newly suggested “critical” symmetries which occur in transitional nuclei when the shape changes from spherical to deformed.

New modes of collective motion are also expected in connection with the formation of a neutron skin, namely oscillations of the skin against the core, similar to the soft dipole mode already identified in the case of very light halo nuclei. Presently, neither the thickness nor the detailed properties of the neutron skin of exotic nuclei are known. This information is needed to enable a quantitative description of compact systems like neutron stars, where exotic nuclei forming a Coulomb lattice are immersed in a sea of free neutrons, a system which is expected to display the properties of both finite and infinite (nuclear matter) objects.

The key role of radioactive beams in the field of nuclear astrophysics is mainly related to the production of heavy elements (A > 60) in the Universe. Stellar Nucleosynthesis above Fe proceeds mainly through neutron capture in different sites, involving a wide range of neutron density, temperature and other stellar conditions. About half of the elements beyond Fe are produced via the r-process (rapid capture, so called because of the very short neutron capture times involved), leading to the production of very unstable nuclei, which only after production by neutron irradiation, decay back to the stability valley. Explosive scenarios, characterized by extremely high neutron densities and temperatures, such as Supernovae and X-ray bursts, are at present considered the most probable sites in which rapid capture processes occur. However, the exact sites and mechanism of r-process nucleosynthesis is at present still largely uncertain. The radioactive beams of SPES should allow one to extend measurements deep into the r-process region.

Despite the large number of experimental studies, so far it is still not possible to predict reliably the limits of nuclear stability or the behaviour of the Nuclear Equation of State (NEOS) at low and high baryon densities.

In particular, the asymmetry term in the NEOS is largely unknown but in the region close to saturation. However, it is just this energy which plays an important role in setting the stability limits. For this reason, it is quite challenging to investigate the behaviour of nuclear matter far from stability. Although the energy range is somewhat limited for studies of this kind, the neutron-rich ion beams of SPES will allow one to further extend the investigation of the NEOS along the isospin coordinate, in a region where it is largely unknown at low as well as high excitation energy.

Since years, the Italian community is at the forefront of most of the above fields at a competitive international level, as demonstrated by many recent experimental and theoretical activities, large collaborations, and initiatives which are in progress at LNL, LNS, and in several INFN Divisions. As a consequence, this community looks at SPES as a European pole of excellence in nuclear physics research for several years after its completion.

2. Facility overview

The proposed facility has two main goals: to provide an accelerator system to perform forefront research in nuclear physics by studying nuclei far from stability and to develop an accelerator based interdisciplinary research centre.

The SPES project is concentrating on the production of neutron-rich radioactive nuclei with mass in the range 80-160 by the Uranium fission at a rate of 10^{13} fission/s. The emphasis to neutron-rich isotopes is

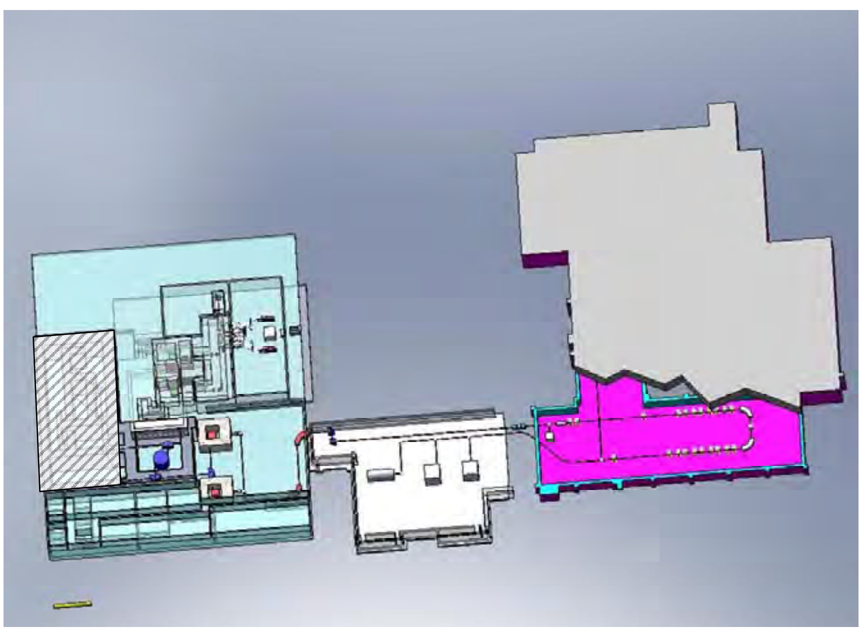

Fig. 2.1 *SPES lay-out (yellow bar=10 m).*

justified by the fact that this vast territory has been little explored, at exceptions of some decay and in-beam spectroscopy following fission. Therefore, reactions in inverse kinematics will allow a new class of data to be obtained. The Rear Ion Beam (RIB) will be produced by ISOL technique using the proton induced fission on a Direct Target of UCx. The proton driver is a Cyclotron with variable energy (15-70 MeV) and a maximum current of 0.750 mA upgradeable to 1.5 mA and split on two exit ports.

The second goal of the facility is achieved by the use of the second high energy proton beam for applied physics and by developing an accelerator based Neutron Facility using the high proton current produced with the TRASCO injector, that is in an advanced construction phase and it is able to deliver a proton beam of 30mA 5MeV. The Neutron Facility has two main applications: the development of a Boron Neutron Capture Therapy (BNCT) installation to perform research in the treatment of cancer and an irradiation-facility (LENOS) for material research and cross section measurements. The expected neutron beam has a fluency of thermal neutrons of 10^9 n cm^{-2} s^{-1} and a rate of fast neutrons of 10^{14} n s^{-1}.

The radioactive beams, in selected forms, are also valuable tools for biological and medical research in the field of cancer therapy.

The SPES facility is designed to supply a second generation of exotic beams able to perform a step forward toward EURISOL and to offer a powerful accelerator based system for research in Astrophysics, Medicine, Applied Physics and Material Science.

The most critical element of the SPES project is the Direct Target. Up to day the proposed target represent an innovation in term of capability to sustain the primary beam power. The design is carefully oriented to optimise the radiative cooling taking advantage of the high operating temperature of the target system that is in the order of 2000^{o}C.

An extensive simulation of the target behaviour has been performed to characterize the thermal properties and the release process. Experimental work to bench mark the simulations was carried out at HRIBF, the Oak Ridge National Laboratory ISOL facility (USA).

The production target is designed following the ISOLDE and EXCYT projects and special care will be devoted to the safety and radioprotection of the system. According to the estimated level of activation in the production target area of 10^{13} Bq a special infrastructure will be designed. The use of up-to-date techniques of nuclear engineering will result in a high security level of the installation. The radiation management and the control system will be integrated and redundancies will be adopted in the design.

The isotopes will be extracted and ionized at 1^+ with a source directly connected with the production target. Several kinds of sources will be used according to the beam of interest. A laser source will be implemented in collaboration with INFN-Pavia with the aim to produce a beam as pure as possible.

The selection and the transport of the exotic beam at low energy and low intensity is a challenging task. Techniques applied to the EXCYT beam will be of reference for the beam diagnostic and an online identification station will be part of the diagnostic system.

To optimize the reacceleration, a Charge Breeder will be developed to increase the charge state to N^+ before to inject the exotic beam in the PIAVE Superconductive RFQ which represents the first re-acceleration stage before the injection in ALPI. The proper velocity matching to enter PIAVE will be

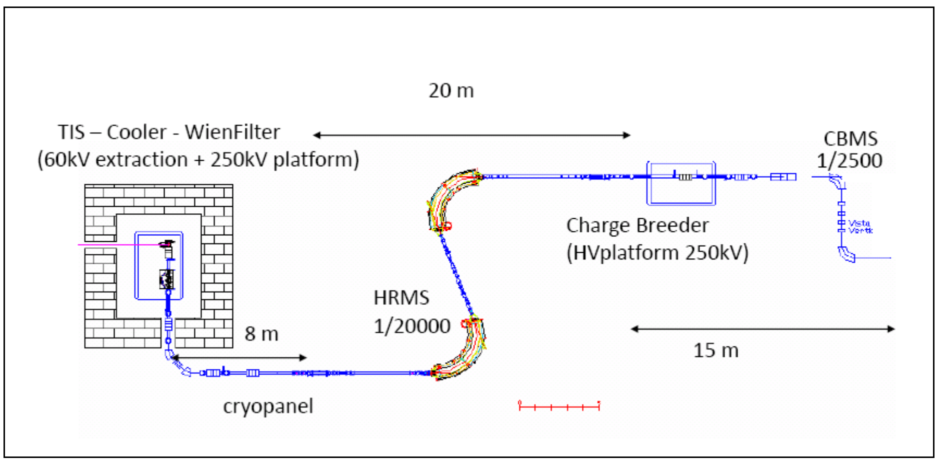

Fig. 2.2 *Basic components of the exotic nuclei production transfer line*

accomplished by HV platforms operated around 250kV.
The expected beam on experimental target will have a rate on the order of 10^8-10^9 pps for ^{132}Sn, ^{90}Kr, ^{94}Kr and 10^7-10^8 pps for ^{134}Sn, ^{95}Kr with energies of 9-13 MeV/u.
The SPES lay-out is shown in figures 2.1 and 2.2. The blue area in figure 2.1 has to be constructed to house the cyclotron proton driver, the two RIB targets, the high intensity proton linac with neutron facility and the target development laboratory. The extension building for the second proton beam from the cyclotron (dashed area) is planned, but out of the scope of the present project.
In figure 2.2 is sketched the transfer line of the exotic beam. The general configuration follows the EXCYT facility. The production target and the first mass selection element are housed in a high radiation bunker and mounted on a high voltage platform; before the High Resolution Mass Spectrometer (HRMS) a cryopanel is installed to prevent the beam line to be contaminated by radioactive gasses, after the HRMS the selected isotope is stopped inside the Charge Breeder and extracted with increased charge; before to reach the PIAVE-ALPI reaccelerator a final mass selector (CBMS) cleans the beam from the contaminations introduced by the Charge Breeder itself.

3. Performances

To determine the beam available for experiment in an ISOL facility, several factors have to be considered. The production of isotopes inside the primary target is the first ingredient but a crucial point, as we are dealing with radioactive species, is the target release time, i.e. the time needed by the reaction products to reach the ionization source from inside the target grains, where they are produced. Than, following the path from production to reacceleration, several efficiencies have to be considered.
The in-target Yield for Nuclear Physics experiment at SPES has been determined starting from the production yield (fission fragment distribution), which was calculated mainly through a Monte Carlo simulation based on transportation model MCNPX. This simulation allows a detailed 3D definition of the system to be analysed and a full transport calculation starting from the proton distribution.
The target is designed with the aim to reach a fission rate of about 10^{13} fission/s. This value is considered a challenge and requires a proton beam of 40 MeV 0.2 mA impinging onto a UCx target; this means that a beam power of 8 kW has to be managed.
To evaluate the exotic beam on experimental target we considered a target material similar to the ISOLDE one and, according to the target geometry, a release time of 2s for Sn isotopes was evaluated with Montecarlo codes (GEANT4 and RIBO) using the available experimental data of ISOLDE, ORNL and Gatchina.
To evaluate the final beam-on-experiment a number of efficiencies were considered: source ionization and extraction, charge breeding, beam transport and reacceleration. We assumed 1+ and N+ (charge breeder) ionization efficiencies equal to 90% (1+) and 12% (N+) respectively for Kr and Xe, but only 30% (1+) and 4% (N+) for Zn, Sr, Sn, I and Cd. The Linac ALPI transmission efficiency is considered 50%.
Using these quantities an evaluation of the beam currents on target for the SPES facility were performed and results are shown in figure.3.1 for some isotopes. To give an indication on the SPES peculiarity would be nice to present a comparison with others facilities. This is a complicated task as, to perform experiments with exotic beams, the beam intensity is not the only important parameter but beam purity and beam energy are also crucial.Nevertheless we report in table 3.1, for sake of comparison, some world-wide ISOL facilities both with Direct and Conversion (p→ n) targets looking to several parameters. It has to be stressed that neutron rich species are available only using fission targets while proton rich are mainly reached with spallation reactions.
ISOLDE-CERN and HIBF-ORNL are, up to now, the only facilities able to produce reaccelerated neutron rich beams. In colour are indicated facilities under construction and expected to be operative in the next 5-6 years.
SPES compares well within the international scenario of ISOL facilities for neutron rich beams both for the fission rate and the energy of the reaccelerated beams.

4. SPES ISOL facility

The basic elements of the ISOL facilities are the primary accelerator, the production target coupled to the ion source (TIS), the charge breeder (or the charge exchange system), the beam transport system and the re-accelerator. According to the requirements of the experimental needs a High Resolution Mass Spectrometer (HRMS) can be part of the transport system. SPES is designed to have a Cyclotron as proton driver accelerator able to supply at least 40 MeV 0.2 mA proton beam onto a UCx direct target.
The ion source is a surface ionization source with the possibility to add a laser ionization device to improve ionization selectivity with the aim to produce high purity exotic beams. For this purpose a HRMS with a mass resolution 1/20000 is also planned.
To reach the charge state and ion velocity that fit the requirement for injection into the PIAVE-ALPI

Table 3.1

	Primary beam	Power on target	target	Fission s^{-1}	Reaccelerator	AMeV A=130 20+	^{132}Sn rate
ISOLDE	p 1-1.4 GeV 2 mA	0.4 kW	Direct&Conv	**$4 \cdot 10^{12}$**	Linac	3	10^{7}
HRIBF	p 40 MeV 10 µA	0.4 kW	Direct	**$4 \cdot 10^{11}$**	Tandem 25MV	4	$2 \cdot 10^{5}$
TRIAC	p 30 MeV 3 µA	0.9 kW	Direct	**10^{11}**	IH Linac	1	$3\ 10^{5}$
HIE ISOLDE upgrade			Direct&Conv	**$4 \cdot 10^{12}$**	SC Linac	5-10	$2 \cdot 10^{8}$
HRIBF up-grade	p 54 MeV 20 µA	1.8 kW	Direct	**10^{12}**	Tandem 25MV	4	$5 \cdot 10^{5}$
SPIRAL2	d 40 MeV 5mA	200 kW	Convert.	**10^{14}**	Cyclotron	6	$2 \cdot 10^{9}$
SPES	p 40 MeV 200 mA	8 kW	Direct	**10^{13}**	SC Linac	10	$3 \cdot 10^{8}$
SPIRAL	C-Kr 95 AMeV	6 kW	Direct		Cyclotron		
TRIUMF	p 450 MeV 70 mA	17 kW	Direct		SC Linac		
CRC UCL	p 30 MeV 300 mA	9 kW	Direct		Cyclotron		
EXCYT	13C 45 AMeV	0.5 kW	Direct		Tandem 15MV		

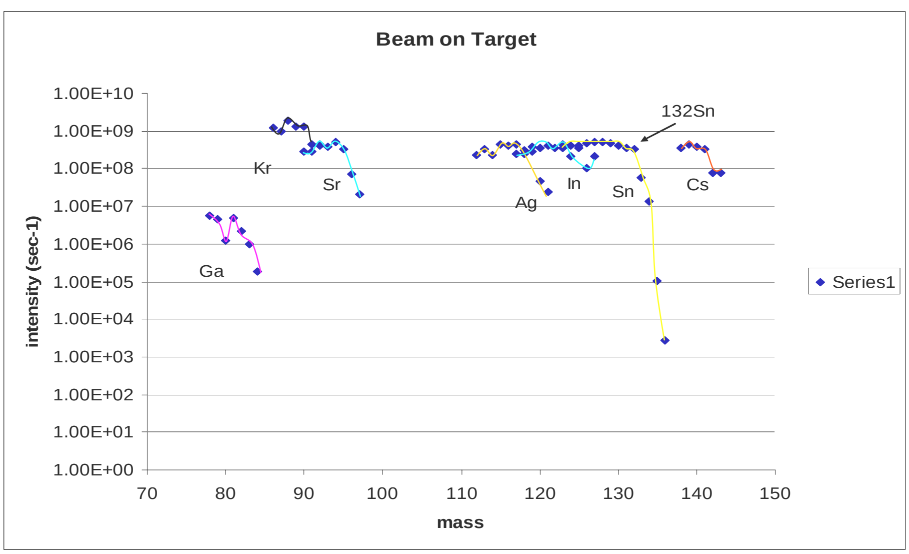

Fig. 3.1 *Beam on target: Intensities calculates considering emission, ionization and acceleration efficiencies (see text) for different isotopes.*

acceleration system a Charge Breeder and 2 High Voltage platforms (HV~250kV) will be used. The first platform will host the TIS and first stage mass separator, the second the Charge Breeder.
As the facility will handle radioactive species, special care is devoted to the radiation protection safety and several systems are added to prevent radiation hazards. A cryopanel device is used to collect not ionized species coming out from the Target Ion Source system and a closed circuit is adopted for the vacuum system gas exhaust. Closed circuits with heat exchange are also used for the cooling fluids of TIS and beam transport system where activation problems can arise. High radiation areas, like the TIS bunker, are ventilated through a nuclear ventilation system with at least two levels of depression to prevent the escape of activated aerosols. A Control System will integrate in a homogeneous architecture the many subsystems necessary for the operation of the facility: from the accelerator control to the radiation and safety survey.

Proton driver

To reach a fission rate of 10^{13} fission/s with a proton beam impinging on a UCx direct target, it is necessary to have an accelerator with the following characteristics:

- Energy of the order of 40-50 MeV
- Minimum current 200 μA (~ $1.2*10^{15}$ p/s)
- Beam spot size on the target Φ 40 mm
- (circle area 1260 mm^2)
- Primary proton flux ~$1*10^{12}$ p/(mm^2*s)
- Beam uniformity on the target ± 1%
- Beam time structure CW to minimise the target thermal stress and fatigue
- Beam intensity stability on target
    - Fast (time scale μs)± 10%
    - Medium (time scale s)± 1%
    - Slow (time scale min)± 1%
- Machine reliability90% of scheduled working time

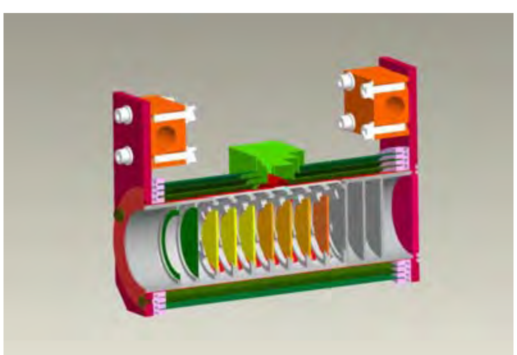

Fig. 4.1 *Direct target configuration (the 7 UC_x disks are shown in yellow and red)*

- Machine availability≥ 5000 h/Y

On top of the previous specification, as open options for future upgrades, it is required to the primary accelerator system (from now on defined as Driver): to be able to serve contemporary users (two or more); to be able to deliver in excess of 1.5 mA of proton beam current; to be able to deliver deuteron and α beams. Both LINAC and CYCLOTRON can satisfy the SPES requirements.

Advantages and disadvantages of the two solutions have been thoroughly evaluated by the design group and by the SPES Steering Committee, taking into account that a R&D on high current proton source and RFQ are going on at LNS and LNL for the TRASCO project.
The conclusion of this analysis was that although both solutions are able to guarantee the required performances for RIB production, including the possibility of a second user beam line feeding, the cyclotron solution has the advantage to be completely independent, leaving the possibility of full time use of the high intensity RFQ beam (5 MeV, 3 mA) as driver for the neutron facility devoted to astrophysics, medical and interdisciplinary applications. The choice of a commercial solution is also dictated by practical reasons, mainly the limited human resources for the design phase and lack in time.
The cyclotron technology is so mature that the market already offers "off the shelf" integrated solution for the medical isotope production with the beam energy and beam intensity figures very close to the SPES requirements (e.g. ≈ 1 mA, ≈ 30 MeV protons). A possible commercial cyclotron, having specifications well fulfilling the requirements of the SPES project, was recently developed by IBA: it is the Cyclone® 70 (C70). This cyclotron prototype is currently under construction at Nante (F) and can deliver protons, deuterons and alphas; the first beam is expected within this year.

Direct Target and Ion Source

The target is designed as a multi-disk target optimized from the point of view of power dissipation, release time of the fission products and Uranium content.
The target is split into several disks (each ~1 mm thick by 4 cm diameter) increasing the total thermal exchange surface and the disks are separated accordingly to allow the cooling of the system by thermal radiation.
The advantage of this configuration is the simplicity of the cooling system and the consequent relatively low cost.
UCx disks are used only where the proton energy has useful cross section for fission, according to the

stopping power, and graphite is used for the last disks. It result in a total amount of 28 g of U distributed into 7 disks.

Figure 4.1 shows the design of the target.

A detailed study has been performed to evaluate the thermal behaviour of the target using the following constrains:

- the incident 40 MeV proton beam has a current of 0.2 mA. The beam profile spans uniformly over a circle distribution, which matches the disk radii of 4 cm;
- the window, necessary to separate the proton beam line from the target void regions, is made of one (or two) thin carbon foil of 400 μm total thickness;

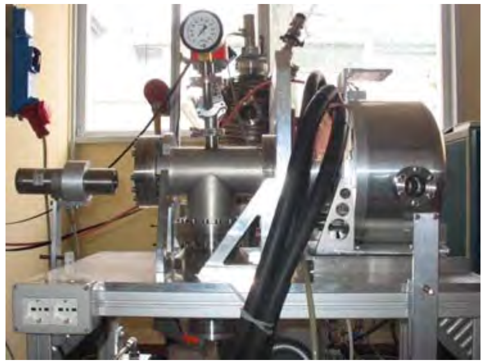

Fig. 4.2 *Prototype of the SPES Target-ion source system*

Table 4.1 Exotic beams available at SPES with Surface Ionization and Laser Ionization sources

Element	Mass	Most Intense isotope (1/s)	Ionization Eff (%)	Target	Source Surface Ionization Laser Ionization	R&D (difficulty)
Ni	65-69	10+6	6	UCx	LIS	**
Cu	66-76	10+6	7	UCx	LIS	**
Zn	72-79	10+6	5	UCx	LIS	**
Ga	72-84	10+6	20	UCx	LIS	**
Ge	75-84	10+7	3	UCx	LIS	***
Rb	86-94	10+9	65	UCx	SIS	*
Sr	89-96	10+8		UCx	SIS+LIS	***
Y	90-97	10+7		UCx	LIS	****
Pd	111-118	10+7		UCx	LIS	****
Ag	110-120	10+8	14	UCx	LIS	**
Cd	115-124	10+8	10	UCx	LIS	**
In	116-128	10+8	15	UCx	SIS+LIS	**
Sn	123-134	10+9	15	UCx	LIS	**
Sb	124-135	10+8	3	UCx	LIS	***
Te	129-138	10+7		UCx	LIS	****
Cs	134-144	10+9	85	UCx	SIS	*
Ba	139-146	10+8		UCx	SIS+LIS	***
La	141-145	10+6		UCx	SIS+LIS	***

- the UC_x target (about ρ=2.5 g/cm^3) is made of seven disks about 1.3 mm thick each;
- the beam dump is made of three carbon disks about 0.9 mm thick each;
- the box containing the disks is made of graphite.
- the operating temperature is 2000 °C

Both an ENEA code and ANSYS code were used to analyse the target thermo-mechanical behaviour and experimental tests of the target principle were performed at the HRIBF facility (ORNL-USA). The main result is that, in the adopted configuration, the target doesn't melt and to reach the operating temperature it is necessary to supply external power.

A strong R&D program is under development on the Direct Target subjects for material, characterization techniques and prototyping. The possibility to produce disks of carbides with the right dimensions has been proved developing and characterizing LaC and UCx pellets.
Collaborations with ISOLDE (CERN) and HRIBF (ORNL) have been established as well as participation to the EURISOL Task3.
The TIS system is developed following the EXCYT and ISOLDE design, a prototype is shown in figure 4.2. The choice for SPES project to develop a Target-Ion Source Chamber unit based on the ISOLDE one, implies the possibility of using a great part of sources developed at CERN. The choice of ion source to be used has primarily been dictated by efficiency and secondarily by its capability of selective ionization.
We consider three kind of ion sources for SPES: the Surface Ion Source, the Forced Electron Beam Induced Arc Discharge (FEBIAD) and the Resonant Ionization Laser Ion Source (RILIS). All of these three sources are used at ISOLDE and they constitute a good reference point for further SPES goals in the ion-source development. The first version of the SPES TIS will be equipped with a Surface Ionization Source with the option to couple a Resonant Ionization Laser Ion Source as a second step in source development.
Using this source set-up the species that can be produced are reported in table 4.1, the last column give a rough indication of the R&D necessary to develop the beam according to the several factors as efficiency and purity.

High Resolution Mass Spectrometer

The secondary beam line transport system will handle the radioactive beam from the output of the ionization source to the low-energy experimental area and to the re-accelerator complex. One of the main problems to operate an ISOL facility is the beam purification since the extracted species are transported according to their M/q value. Due to the low rigidity of the beam, electrostatic quadrupoles can be used to focus and transport the beam. This guarantees a reliable beam handling and a very simple procedure to set the beam transport line.
The beam extracted from the source with 50kV extraction potential, will cross through a first stage of m/z purification, which allows trapping the largest amount of radioactive contaminant. According to other facility, and to satisfy the previous constraint, we plan to use a small Wien filter, placed on the first HV platform just beyond the source. Furthermore a small magnetic dipole, like in the EXCYT design, can be also used. A mass resolving power (M/ΔM) of 300 for this “analytical” magnet is acceptable.

Table 4.2 Main parameters of the HRMS for SPES project compared to the EXCYT one

Project name	EXCYT	SPES
Number of dipoles	2	2
Bending Angle	90°	110°
Bending radius	2.6 m	2.6 m
Entrance/exit angle	12.8°	32°
Magnetic field range	0.6 - 4.4 kGauss	1.0 - 4.4 kGauss
beam size at analysis slits	0.4 mm	0.4 mm
Teta acceptance	40 mrad	40 mrad
(x,x’) emittance	4 π mm.mrad	4 π mm.mrad
Y beam size	2 mm	2 mm
Phi acceptance	10 mrad	10 mrad
(y,y’) emittance	4 π mm.mrad	5 π mm.mrad
Resolving power	>15.000	>20.000
Dispersion	16 m	28 m

It will be followed by a 1/20000 High Resolution Mass Spectrometer (HRMS) which allows the isobar selection. To improve the selection capability HRMS shall operate at an input energy in the order of 200keV. To fulfil this requirement the HV platform, where both target and first mass separator are mounted, is operated at 200kV supplying 1+ beam at total energy of 250keV. The design of the HRMS follows the EXCYT one and the main parameters are reported in table 4.2
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 Superconductive RFQ, which represents the first re-acceleration stage before the final injection in ALPI.
The Charge Breeder acts as a trap where the 1+ ions are stopped and re-extracted with increased charge state. To fulfil these requirements the Charge Breeder is mounted on a second HV platform operated at 250kV; this allows to stop the incoming ions and to give the right energy to the out coming ones.

PIAVE-ALPI re-accelerator

The reacceleration of the exotic species will be performed by the acceleration complex PIAVE-ALPI.
PIAVE is an injector designed to accelerate ions with A/q=<8.5 up to 1.2 MeV/u. It is based on an ECR Ion Source (placed on a 350 kV platform), and on super-conducting RFQs. Since fall 2006 it is in regular operation at LNL.

For the SPES project a transfer line from the Charge Breeder will be added. No main difficulties are expected as the ions coming from the Charge Breeder have characteristics similar to that one produced actually in the ECR.

The linear accelerator ALPI, with a β range between 0.04 and 0.2 and CW operation, represents an ideal re-accelerator for the radioactive beams. Radioactive ions can be accelerated above the Coulomb Barrier with high efficiency. The quasi-continuous time structure and the possibility to adjust finely the output energy make it very well suited for nuclear physics experiments. A time structure suitable for TOF measurements can be implemented by a low energy bunching system.

ALPI underwent a number of significant upgrades, in recent years, which made it a world-class facility in heavy ion stable beam accelerators and which will represent an important added value for its use as a RIB accelerator as well.

The figure 4.3 shows the increase of the equivalent voltage V_{eq} of ALPI along the years. In the histogram, the contribution to V_{eq} by the medium beta Pb/Cu resonators, which were progressively replaced by Nb/Cu ones, can be noted. The contributions of the Nb/Cu high beta and of the full Nb low beta resonators are also shown.

With the aim to increase the final energy a first test with an external stripper station, located at 1/3 of ALPI, were successfully performed during 2008.

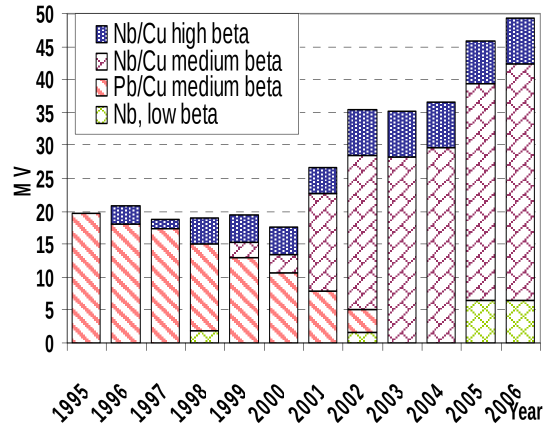

Fig. 4.3 *Increase of the equivalent voltage V_{eq} of ALPI along the* years

The final ALPI energy can significantly increase according to the higher charge state produced in the stripper, the drawback is a ~70% transmission reduction due to the stripper itself.

A further improvement of the final energy is possible with the installation of additional 6 cryostats with 24 high beta cavities.

A summary of the SPES beam energy is reported in table 4.3 which summarise the final energies of some isotopes according to the charge state and the ALPI acceleration capability.

Table 4.3 *Energy of selected beams on target according to relevant parameters: the acceleration voltage of the ALPI cavities and ion charge state. The performances of the ALPI superconductive cavities have been improved in the last years changing the technology from Pb to Nb. The last set of high beta cavities (Cryostats 21-26) is not actually installed.*

Year		2006	2007		2008		
E_{acc} [MV/m]	CR03	0	0	0	6	6	6
	CR04->CR06	3	3,5	3,5	3,5	6	6
	CR07->CR20	3,6	3,6	4,2	4,5	4,5	4,5
	CR21->CR26						5,5
Energy [MeV/A]	$^{238}U^{28+}$	4,96	5,21	5,84	6,2	6,6	9,9
	$^{132}Sn^{16+}$			6,7	7	7,5	10,3
	$^{132}Xe^{19+}$	6,13	6,39	7,15	8	8,9	12,1
	$^{132}Xe^{26+}$			9,6	10,8		16,1
Energy [MeV/A] with stripper	$^{132}Xe^{40÷44+}$	9,1		10,6	12,8		20
	$^{132}Xe^{41÷45+}$			13			22,8

5.SPES Neutron facility and applications

It is part of the SPES project the construction of a high intensity linac system based on the TRIPS proton source and the TRASCO RFQ able to produce a proton beam of 30mA 5MeV.

This accelerator system is well suited for the development of a proton and neutron irradiation facility which covers several application and fundamental research areas.

Neutron beams of thermal or fast neutrons are obtained using suitable converters and moderators.

In the last years a renewed interest in the low energy neutron physics has triggered the construction of new facilities as well as many experimental apparata. This process has been mainly boosted by the needs of nuclear data in several fields like nuclear astrophysics, nuclear waste transmutation, generation IV reactors, fusion reactors, decommissioning of first generation fission reactors, radioprotection, dosimetry and by medicine and material science communities. For this reasons a great number of facilities have been built or are in preparation all over the world: n_TOF (CERN), Frankfurt (Germany), Obninsk and INR-Troitsk (Russia), JPARC (Japan), SNS and LENS (USA) just to cite some of them.

The SPES project aims the development of two accelerator-based neutron beams facilities using the high intensity linac: the first one exploiting a high intensity neutron source rate of 10^{14} n/s to provide a thermal neutron beam flux of 10^9 n cm^{-2} s^{-1} at least. The second one, exploiting the same neutron converter or a different one, to provide a fast and/or epithermal spectrum beam facility.

The main application of the thermal neutron beam will be the BNCT project for the study of the Boron Neutron Capture Therapy technique applied to the skin melanoma disease, whereas the irradiation facility LENOS is devoted to Astrophysics and applied sciences.

Further applications of the SPES facility are related to the high energetic neutrons obtained by the high energy proton beam of the cyclotron and to the direct use of the produced radioisotopes for biomedical applications.

TRASCO Proton driver

To develop an accelerator-based neutron facility a high current proton Linac is proposed with a beam of 5 MeV, 35mA with a continuous wave duty cycle (cw). The proton driver is based on a room temperature radiofrequency quadrupole (RFQ) and an ECR source. The main elements of the LINAC are the off resonance ECR source (TRIPS), and the high current radio-frequency quadrupole (RFQ). The ion source, built and commissioned with beam at LNS, is now in operation at LNL. The main working parameters of the TRIPS source are summarized in table 5.1 comparing the design requirements with the actual measured values.

The RFQ consists of three segments 2.4 meters long each, resonantly coupled via two coupling cells in order to reduce sensitivity to machining errors. Each segment consists of two 1.18 meters long modules, which are the basic construction units. Two of the six modules are completed, for the other four the high precision machining is completed and they are waiting for the brazing to be done at CERN. If necessary the RFQ structure, with the cooling capability necessary for cw operation, can be pulsed with a large margin of redundancy.

The main parameters of the RFQ are listed in Tab. 5.2; the operating frequency is 352.2 MHz, with the design choice of using a single 1.3 MW klystron.

Table 5.1 *TRIPS main working parameters*

	requirements	**Status**
Beam energy	80	80
Total current (mA)	70	60
Proton fraction (%)	90	≈85
Microwave power (kW at 2.45 GHz)	<2	0.3-1
Duty factor (%)	100 (dc)	100 (dc)
Beam emittance (π mm mrad)	≤0.2	~0.07
Reliability (%)	~100	90 % at 30 mA
Gas flow (sccm)	<2	0.4-0.6

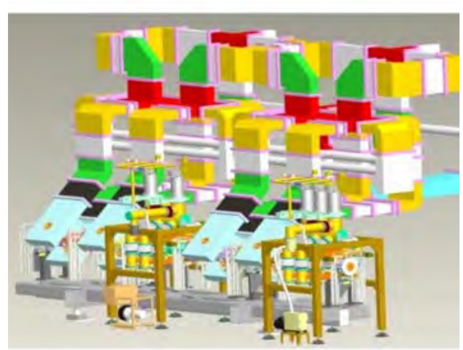

Fig. 5.1 *3D view of the complete layout of the RFQ waveguide system.*

***Table 5.2** Physical RFQ parameters*

Energy Range	0.08-5	MeV
Frequency	352.2	MHz
Beam Duty cycle	100 (CW), 1 (pulsed)up to 100%	%
Maximum Surf. Field	33	MV/m (1.8 Kilp.)
Emittance T RMS in/out	0.2/0.2	mm mrad norm.
Emittance L RMS	0.18	MeV deg
RFQ length	7.13	m (8.4 λ)
Intervane voltage	68	kV
Transmission	96	%
Modulation	1-1.94	
Average Aperture R_0	2.9-3.2	mm
Synchronous Phase	-90÷-29	Deg
Dissipated Peak Power SF*1.2	0.579	MW
Q (SF/1.2)	8261	
Peak Beam Loading	0.1476	MW
Peak RF Power	0.726	MW

The RF power will be fed by means of eight high power loops as shown in figure 5.1. The main components of the RF system are parts of the former LEP RF system. They are recovered from CERN together with 2 klystrons and are actually stored at LNL. The second klystron is for spare or facility upgrade.

The SPES BNCT project: a thermal neutron beam facility for skin melanoma experimental treatment

BNCT is the acronym of Boron Neutron Capture Therapy, a binary radiation therapy. First, a boronated substance is injected in the patient body, then the patient is irradiated with thermal or epithermal neutrons. The boron transport molecule is harmless and designed to be preferably up taken by tumour cells. Because of the high ^{10}B thermal neutron capture cross section (3837 barn), the nuclear reaction $^{10}B(n,\alpha)^7Li$ is likely to occur. The nuclear reaction fragments thus produced (^4He of 1.47 MeV and ^7Li of 0.84 MeV) are densely ionizing charged particles, the ranges of which in soft tissues (~8 µm for the α particle, 5 µm for the lithium ion) are as short as a cell diameter (~10 µm). Therefore, only those cells containing ^{10}B are damaged, while the healthy surrounding ones remaining undamaged. Such a peculiar behaviour of energy releasing allows of conceiving a cellular radiation therapy, which is very useful whenever the tumour cells migration occurs from tumour bulk in the healthy tissue extensively. In order to exploit such a nuclear reaction in radiation therapy, a large research activity is going on in Europe, Japan as well as United States which aims at providing optimal ^{10}B carriers targeting the tumour cells as well to optimize the radiation dosimetry.
Patients have been treated for malignant skin melanoma (MM) with good therapeutic results at Kyoto University and recently at the irradiation

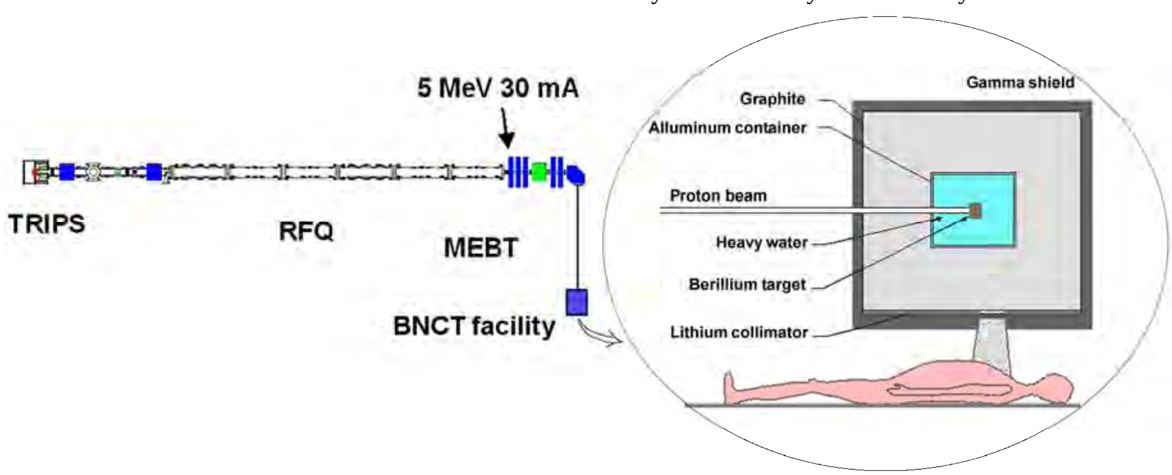

***Fig5.2** Schematic layout of the accelerator-driven SPES-BNCT irradiation facility*

facility of the Bariloche reactor in Argentina on 2004. The research is going on since '80, nevertheless available reports and retrospective studies clearly show that the method offers great opportunities but it is not standardized. Moreover, published reports are not exhaustive. One of the current limits for the therapeutic plan optimisation is the poor knowledge about the maximum damage that healthy tissue can sustain, which implies a maximum in the radiation-field exposition, and the poor characterization of the beam according to the biological effectiveness. For such a reason research is going on to perform radiobiological and microdosimetry measurements and to improve the radiation quality assessment of BNCT and other hadronic beams.

The goal of SPES BNCT project is to get an advance in the experimental treatments on MM with new fundamental goals: the construction of the first, accelerator-based, high flux thermal neutron beam facility, the use of a new, innovative dosimetry approach based on the microdosimetry technology never tested before in clinical trials, as well as the research for new MM-highly-selective Boron carriers. Till now, no other international BNCT projects have the peculiarities of SPES-BNCT.

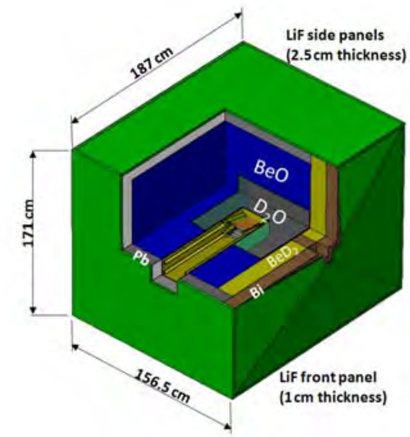

Fig.5.3 *The best configuration proposed for the neutron moderator with the final Be neutron converter inside: MCNPX geometry*

Table 5.3 *Neutron converter irradiation parameters due to 30 mA, 4 MeV proton beam.*

Neutron source	Thermal neutron fluence rate	Total neutron fluence rate	Continuous operation	Total neutron fluence
$3.15 \cdot 10^{13}$ s^{-1}	$5.0 \cdot 10^{11}$ cm^{-2} s^{-1}	$7.0 \cdot 10^{11}$ cm^{-2} s^{-1}	1600 hours	$1.0 \cdot 10^{19}$ cm^{-2}

Table 5.4 *parameters of neutron and gamma radiation at the exit port*

	Φ_{th} (E≤0.4eV) (cm^{-2}s^{-1})	Φ_{th} / Φ_{total}	K_{nth} (Gy·h^{-1})	$K_{n\ epi\text{-}fast}$ (Gy·h^{-1})	K_γ (Gy·h^{-1})	$K_\gamma / K_{n\ tot}$	$K_{n\ (E>10\ eV)} / \Phi_{th}$ (Gy·cm^2)	K_γ / Φ_{th} (Gy·cm^2)
Ref.	**> 1E+09**	**> 0.90**					**≤ 2E-13**	**≤ 2E-13**
Fase-III	**1.17E+09**	**0.99**	0.70	0.0008	0.58	0.8	**7.93E-16**	**1.38E-13**

The Legnaro BNCT project aims to use the intense proton beam provided in the framework of SPES facility to produce an intense thermal neutron source, by a 150kW Beryllium converter and a multilayer moderator.

A sketch of the facility layout is shown in figure 5.2.

The reaction $^{9}Be(p,nx)^{9}B$ (Q = -1.85 MeV) is exploited producing 3 10^{13} n s^{-1} of average energy 1.5 MeV with the parameters reported in table 5.3.

The neutron moderator is designed with the aid of MCNPX code to optimize the thermal neutron beam at the exit port. A sketch is shown in figure 5.3.

The neutron flux of thermal neutrons at the moderator exit port is evaluated to be ~ 10^{9} n_{th} s^{-1} with a very low contamination of energetic neutrons and gammas, as reported in table 5.4 together with the reference values adopted in the design.

To succeed in BNCT several aspects must be fulfilled: the neutron beam is one but very important are the use of the right molecule to carry boron inside the tumour cells and the possibility to study the microdosimetry experienced by the cell. The several aspects to fulfil the BNCT project are covered by collaboration with the Medicine Department of Padua University, the microdosimetric group at LNL and ENEA by the use of the TAPIRO reactor where experimental work is in progress on the HYTOR facility, a neutron moderation structure designed by LNL and actually in operation at TAPIRO

The LEgnaro Neutron Source LENOS

LENOS aims to construct a neutron and proton irradiation facility for Nuclear Astrophysics and interdisciplinary applications. The facility would exploit the large intensity of the proton beam both for direct irradiation and for the production of a high-flux neutron beam with energy ranging from thermal up to a few MeV with a generated neutron flux of the order of 10^{14} n/s using Beryllium or Lithium neutron converters.

Such an irradiation facility would fulfil the increasing demand of high-flux neutron beams, meeting the needs of a large National and International community for studies related to several interdisciplinary fields, from Astrophysics to bio-medicine, from development of new detectors and electronics to material research.

For *Nuclear Astrophysics* the major addressed item is the measure of the neutron capture cross section, a fundamental ingredient for the calculation of the stellar reaction rates and thus the possibility of reproducing the observed abundance of the elements in the Universe. This is performed with a Maxwellian shaped neutron beam according to the relevant stellar temperatures. In this way the stellar reaction rate can be measured directly by the MACS (Maxwellian Averaged Cross Section). An R&D is dedicated to this subject and a proposal with an innovative technique, based on a proton energy shaped beam, will be ready at the end of this year; a preliminary evaluation of the neutron spectra obtained with degrading the 5 MeV proton beam impinging onto a Li target is shown in figure 5.6.

Unique measurements are possible at SPES where targets of radioactive isotopes built with the ISOL facility using the not re-accelerated exotic beam can be measured on-line at the LENOS neutron facility.

Other applications of the neutron beam is envisaged in the field of *bulk damage studies in semiconductors* detectors and electronics not only for High Energy Physics but also for applications in radiation environments such as Space and Avionics, using thermal and fast (1.5MeV) neutrons.

These studies are currently performed at LNL using ionizing radiations; the new neutron facility will improve the research capabilities and the addressed fields.

Radiobiology and Nuclear Medicine

Radiobiology activity is traditionally an important part of the research programmes of interdisciplinary physics carried out at the INFN-LNL accelerator facilities, since more than 20 years. The experiments are related to the investigation of the biological effects induced by ionizing radiation in cultured (normal and tumour) mammalian cells as a function of radiation quality (i.e. atomic number, Z, mass number, A and energy or LET of ions).

An increasing interest is nowadays related to the biological action of radioactive ions, in particular in the field of hadrontherapy where the direct use of radioactive ion beams has been suggested.

Radioactive beams show additional superiority to tumor treatment by representing double irradiation modality: the external one by primary ion beam itself, the internal one by hadrons (and gammas) emitted in the subsequent radioactive decay.

Another specific application for radioisotopes is for diagnosis and therapy of diseases, by the use of radio-labelled tumor-selective antibodies. The concept of localizing the cytotoxic radionuclide to the cancer cell is an important supplement to conventional forms of radiotherapy.

The growing complexity of imaging methods as PET (positron emission tomography) and SPECT (single photon emission computed tomography) and the developments in systemic radionuclide therapy ask for radioisotope preparations with higher radiochemical and radionuclide purity that has not been achievable before. The production of selected radioisotopes of medical interest can be performed at SPES, by the use of the High Resolution Mass Spectrometer (HRMS), following the research line pioneered by ISOLDE.

In conclusion the SPES Facility will offer unique opportunities to extend the radiobiological activity programme in Italy taking profit of the availability of protons, neutrons as well as selected radioactive ions in a wide energy range.

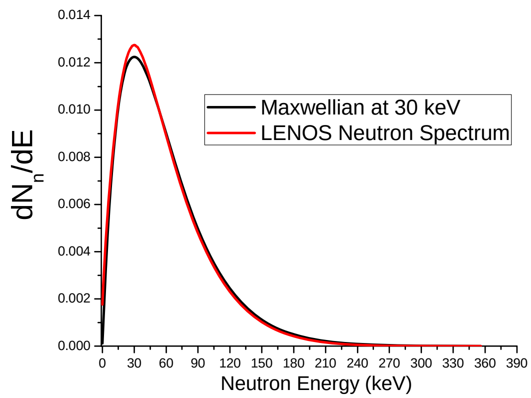

Fig.5.6 *Preliminary evaluation of the neutron spectra for MACS measurements obtained at LENOS with a degraded proton spectra and a Li target.*

6. Infrastructures

The SPES project will require a completely new development of buildings and related services. The design will take care of all the needs requested by the safety and radioprotection rules. Specific study will be carried out by a company with expertise in the domain of nuclear safety and the results of this study can modify the present layout of the infrastructures. LNL has already implemented some preliminary activities to allow the construction.

A new electrical power station has been installed and is under commissioning. It allows a power of 30 MW for the new project and 10 MW for the other activities of LNL The power station has been designed and built in order to give a final power capability of 100 MW. Furthermore the station is linked to the 132 KV RTN in order to reduce the problem of micro interruption (few micro seconds)

The main roads around the area are under completion and the access to the new area is already available. A new technological platform has already been started as well as the tunnel to distribute to the new sites all the technical facilities (compressed air, cooling water, cryogenics fluids). Figure 6.1 shows the actual layout of the Laboratori Nazionali di Legnaro with the existing buildings and the SPES area.

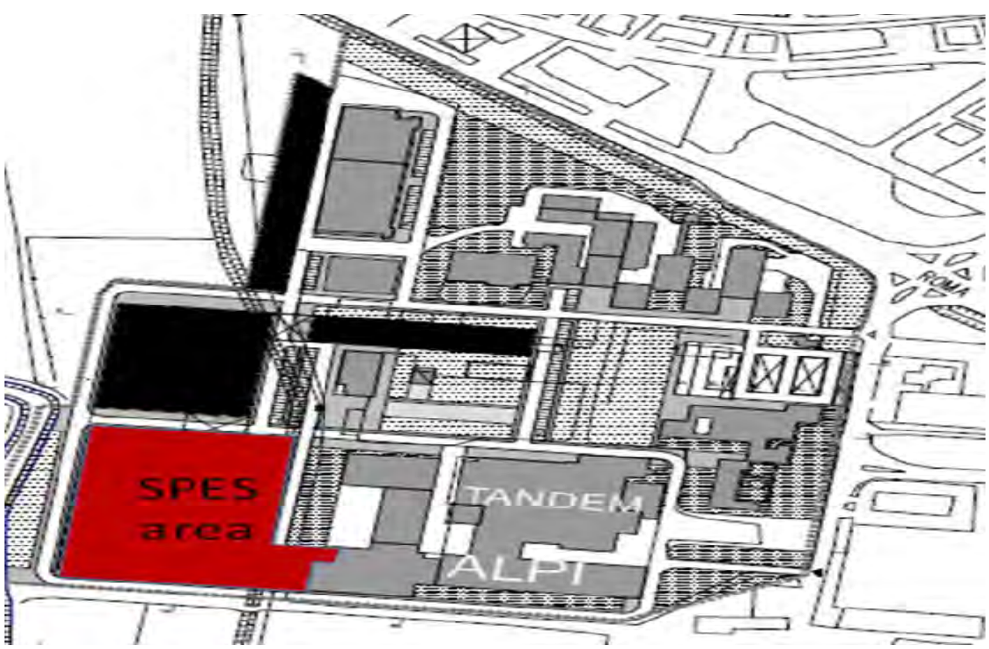

Fig.6.1 *LNL-Layout. In grey the existing buildings, in black planned expansions (step1) in red the SPES area.*

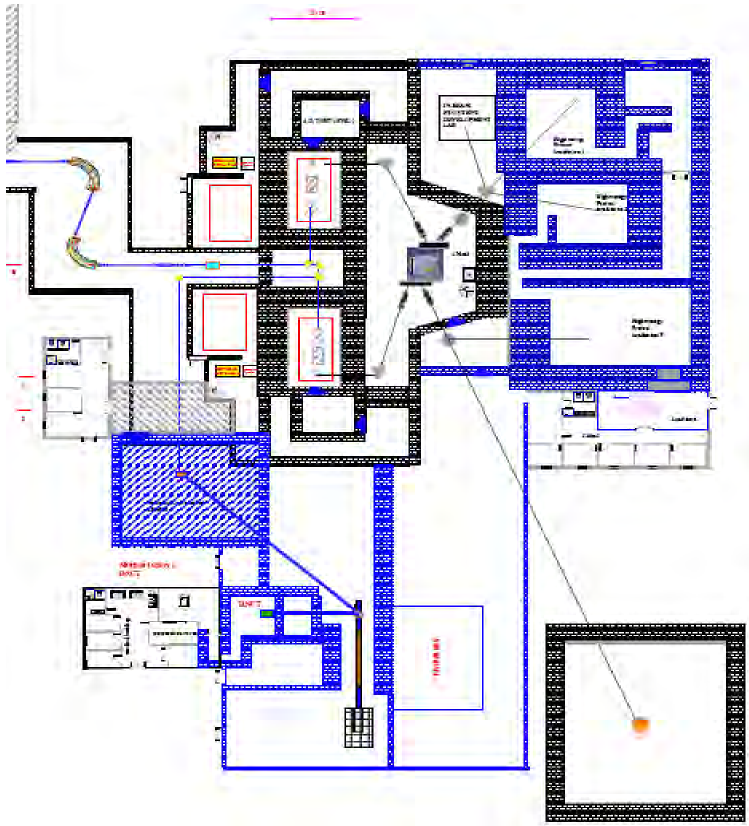

Fig.6.2 *SPES buildings layout*.

A preliminary study checked the feasibility of the project, using on purpose an over designed shielding thickness: in the central part of the building the cyclotron cave has 3m concrete shielding, 6 m height and 150m^2 areas. A 4 m thick concrete bed below the Cyclotron and 3 m concrete roof are planned to avoid radiation problem in the atmosphere and in the soil. A core boring of the ground showed various layers of clay, silt and sand, with the water layer at –2.5 m from ground level. A specific proposal for the construction of the building under these geological conditions has been done.
Special care will be devoted to the construction of the production target building. A solution with double containment will be adopted to increase the safety of the system. A bunker will host the target and source platform. The necessary shielding to maintain the dose outside the bunker on the order of 1.5 μSv/h will be used. This requires a concrete thickness of 2-3 m. Two independent production target stations will be constructed with the aim to operate them in alternate way to optimize the capability to supply beam on experimental target.
Due to the problem related to the air activation by neutrons the bunker will be equipped with a dedicated nuclear ventilation system.

Figure 6.2 shows the buildings layout with the Cyclotron, the two direct targets and the HRMS in the centre and left-up corner; the neutron facility on the left-down corner and the buildings for the high energy proton beam applications on the right side.

7. Radiation Safety aspects

Radiation safety aspects have a major impact on civil construction planning, control system design and special technological plants for the SPES facility.
The main items addressed are the neutron and gamma production by the high energy and high current proton drivers and the radiation activity induced in the Direct Target by the Uranium fission.
The SPES facility will meet the conditions stipulated by the Italian radiation protection legislation following the project guidelines as reported in table 7.1
The shielding for Cyclotron cave and Direct Target bunkers are dictated mainly by the neutron production rate and energy spectra. A shielding thickness of 3 m of concrete is necessary to have an annual ambient dose equivalent much less than 0.5 mSv/y, if concrete of 2.1 g/cm^3 density is considered. A reduced thickness is possible if special concrete or composite materials are used.
At this level of the project the maximum thickness is accounted for. A detailed design will be performed considering any lack of neutron and gamma radiation due to service connections and beam ports.
To avoid the contamination risk by inlet of activated air a nuclear ventilation system will be installed to process the air of Cyclotron cave and Direct Target bunkers.
The activity induced inside the Uranium target is the most severe source of risk. The target activation was evaluated and a shielding and handling system will allow to dismount the target with a remote operation. In table 7.2 is reported the activation of the UCx disks. After 14 days of cooling down, the target can be removed with some care but in quite safe conditions. A minimum shield of 2 cm of lead and an operation distance of 2 m allows an eventual manual operation with a total dose of 1mSv/h. An operation of 5min gives a dose of 83 μSv, quite low respect to the 20 mSv max dose/year of classified personnel.
After 30 days of irradiation, inside the ~30g UCx target are collected about 60 mg of fission fragments and some actinides elements like: U236 (0.34 mg), Np237 (0.52 mg), and Pu239 (5 μg). These elements

Table 7.1 *Limits and project guidelines.*

Type of area	Effective dose (mSv/y)	Project guidelines (mSv/y)	Max. H*(10) rate (μSv/h)
Not classified	1	0.5	0.25
Supervised	6	3	1.5
Controlled	20	10	5

Table 7.2 *Activation of the* UC_x *disks (28.6 g)*

Steps	**Activity (Bq)**	**Dose* gram (Sv/h)**	**Total Dose (Sv/h) at 1 m**	**Total Dose (Sv/h) at 2 m**	**Total Dose (Sv/h) at 2 m with 2cm lead shield**
IRRADIATION					
1 Days	1.50E+13	6.20E-02	1.77E+00	4.43E-01	
4 Days	1.70E+13	6.70E-02	1.92E+00	4.79E-01	
7 Days	1.80E+13	6.80E-02	1.94E+00	4.86E-01	
14 Days	2.00E+13	7.30E-02	2.09E+00	5.22E-01	
COOLING					
1 Secs	2.00E+13	7.26E-02	2.08E+00	5.19E-01	5.19E-02
1 Days	3.33E+12	6.82E-03	1.95E-01	4.88E-02	4.88E-03
3 Days	1.78E+12	3.85E-03	1.10E-01	2.75E-02	2.75E-03
14 Days	6.67E+11	1.44E-03	4.12E-02	1.03E-02	**1.03E-03**
30 Days	1.78E+11	3.85E-04	1.10E-02	2.75E-03	2.75E-04
90 Days	5.00E+10	8.36E-05	2.39E-03	5.98E-04	5.98E-05
10 Years	6.22E+08	5.94E-07	1.70E-05	4.25E-06	4.25E-07
100 Years	1.22E+08	1.01E-07	2.89E-06	7.24E-07	7.24E-08

have a boiling point higher than the target operating temperature and are mainly confined inside the target material. No contamination by alpha emitters is reported at HRIBF, the facility most similar to SPES world wide. From the point of view of the radiation safety the radioactive gasses have to be addressed with attention as in principle they may contaminate the full re-acceleration structure. To avoid this to occur, a number of cryopanels will be installed to allow the gas condensation and a closed circuit will be used for the gas exhaust of the vacuum system with filtering and silos storage.

The SPES radiation protection program reports on the zone classification of the facility and on the access controls. The respect of the radiological zone will be monitored by specific barriers and real-time dose measurement. The access control system and the dose monitoring will be integrated in the facility operation control system to prevent dangerous situations, as loss of primary proton beam over the allowed limits and over-contamination of the facility components. The radioactivity transported in the facility will be continuously monitored. The facility is designed to have at least two barriers between radioactive zone and the environment. Interlock valves ensure the containment of the target and a second barrier is the vacuum system. The target area is inside a two layer bunker with controlled and separate ventilation.

Additional monitoring and bunkers will be added in the existing rooms if necessary, according to the expected radiation level. One of these elements is the Charge Breeder where large part of the exotic beam is lost.

An adequate fire prevention system will be installed in the new buildings and integrated with the existing one. The water used for fire extinguish will be collected in separate sump to allow the radioactivity test before the intake in the exhaust system

The incidental situations will be evaluated and managed in such a way that all significant impacts will be confined inside the site and no hazards to the environment will be introduced. The major incidental situation is related to the sublimation of the target. This can be induced by a malfunctioning of the heating control system or by an error in the primary-beam handling.

The impact on the installation is the contamination of the beam lines downstream from the target and the over-contamination of the vacuum system.

The incident is mitigated by the valves along the beam line that will be closed by the control system alerted by several parameters: the heating of the target (controlled by a pyrometer and thermo-couples), a sudden decrease of the vacuum in the target box (controlled by vacuum measurement).

The accidental situations that may cause a release of radioactive material to outside of the site will be carefully considered and countermeasures will be adopted to minimize the impact on the environment with the goal to reduce the dispersion to 1Bq/gr.

The worst situation is fire in the target bunker. The fire prevention system will act to extinguish the fire without the use of water and the bunker will be permanently closed. All ventilation ducts and the pipelines of the refrigerating fluids will be interlocked. The injured target station will be put off line and the access will be allowed only after a careful evaluation of the contamination eventually present inside the bunker.

The main risk of radioactivity dispersion is related to the ventilation system. The very worst case is that the whole target material is put into suspension and is processed by the ventilation system. In this case the larger part of the particulate is trapped in the HEPA filters, if all gaseous elements are released outside the facility the radiological impact is evaluated to be of 2 mSv without the charcoal filtering and 0.4 mSv if charcoal filters are effective.

No dispersion of radioactivity is expected if the target vessel does not break.

A detailed analysis of the risk will be performed by a specialized company with special regard to the radiation aspects. Generic and specific hazards will be analyzed. Among them earthquake**,** fire**,** overflow**,** explosion will be considered.

8. Organization

The SPES project is organized with a schema shown in figure and table 8.1 .
The Management Board takes care of the project schedule and resource assignment.
The Steering Committee evaluates the project development according to milestones and assigned investment.
The International Review Committee has the mandate to evaluate the adopted technical solutions and the scientific program.
The SPES group is the working group for SPES realization and guaranties the technical and scientific support to the project.

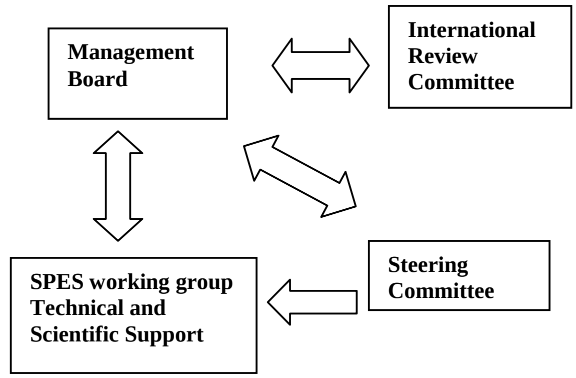

Fig.8.1 *SPES organization: groups and committees*

Table 8.1 *SPES organization*

Steering Committee | **International Review Committee**

Project Leader

Radiation protection coordinator | **Technical coordinator** | **Scientific coordinator**

SPES Working Group (Technical and Scientific Support)					
safety and control	**infrastructure**	**target and beam transfer**	**Accelerator and Neutron Facility**	**Scientific Support**	**Project Management**
Task 1	**Task 2**	**Task 3 4**	**Task 5 6 7**	**Task 8**	
control system architecture	building	ISOL target & source	Cyclotron proton driver	Physics case	Project organization
radiation Protection	civil engineering	development Lab	proton diagnostic	workshops	project secretary
shielding	nuclear engineering	target production	RIB PIAVE-ALPI reacceleration	Letters of Intent and international collaborations	budget monitor
radiation safety	electric power	in-beam and off-line test-bench	RIB diagnostic	Instrumentation	orders preparation
conventional safety	nuclear ventilation	Laser source	High intensity proton source		
accelerator control	fluids	1+ beam transport	High intensity proton RFQ and LEBIT		
target control		high resolution isotope separator	Neutron Facility BNCT-LENOS		
vacuum target and RIB		n+ charge breeder			
waste management					

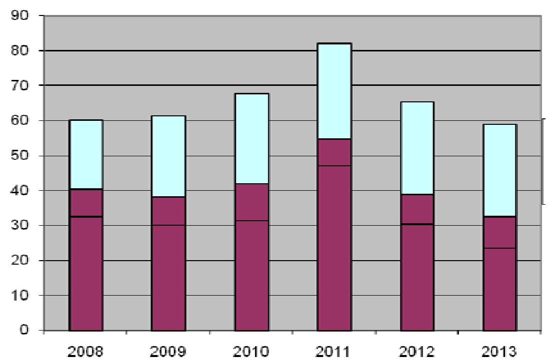

Fig. 8.2 *SPES personnel for construction phase. Available in brown, to be hired in cyanic*

Both committees are nominated by the INFN Board. The Management Board is made up the Project Leader, the SPES Coordinators (Technical, Scientific, Radioprotection) and the Project tasks leaders. The SPES Working Group is structured in 8 tasks to cover all the items necessary for the realization of the SPES project. The requested personnel involve about 70 FTE for 6 years as shown in figure 8.2.

A plan to cover all the needs is under discussion. It is based on two stages: the construction phase, in which are mainly requested post doctoral fellowships all across the collaboration, and the facility operation for which it is expected to completely recover the turn-over at LNL adding 7 new staff positions in the next 6 years.

9. Schedule and cost

The time schedule for the implementation of the facility is shown in table 9.1. Before starting the construction the R&D program will continue for key development subsystems as Charge Breeder and HRMS to receive adequate answers; such items, will be completely mature in about one year.

At the same time the detailed design and the procedure needed for the construction authorization will be implemented.

Design and construction of the facility will require 4 years, with the installation and commissioning of parts of the machine beginning immediately after the completion of the buildings and related infrastructures. Two additional years are necessary to complete the installations and commissioning. Critical parts as RIB target and high current RFQ are in advanced construction stage and will be ready for laboratory test before the building construction. In 6 years the facility should be ready for the first exotic beam on target. The planning considers also the year 2007 as the starting point for the project development in the actual configuration which consider a Direct Target of UCx.

The implementation of the ALPI re-accelerator is also accounted in year 2007, when the modification of low beta cavities started.

Table 9.2 summarizes the cost breakthrough of the entire facility described in the previous chapters; it relates to a cyclotron proton driver with at least 40

Table 9.1 *SPES planning*

	2007	2008	2009	2010	2011	2012	2013
Facility design							
Target prototypes							
Autorization to construction							
Building construction							
Target installation and commissioning							
Completion of RFQ for Neutron Facility							
Installation and Commiss. Neutron Facility							
RIB DRIVER construction							
RIB DRIVER Installation and commissioning							
Alpi preparation for post acceleration							
Installation of RIBs transfer lines							
Complete commissioning							

MeV 200 µA, to a RIB production section based on UCx direct target (two target stations) and to the reacceleration in ALPI upgraded in its low beta section.

Table 9.2 *SPES cost table*

	2008	2009	2010	2011	2012	2013	
							k€
infrastrutture	220	620	5000	8000	700	300	14840
target	1500	1300	1000	750	1050	300	5900
Beam Transfer	400	2350	2100	2000	650	150	7650
safetyRadioprot	250	110	750	2800	1800	290	6000
Cyclotron		2000	2000	2000	1000	1400	8400
Re-accelerator	900	2700	3000	300	100		7000
High Intensity Linac	300	200	1600	700	500	300	3600
Neutron Facility BNCT - LENOS	550	850	500	550	650	200	3300
	4120	10130	15950	17100	6450	2940	56690

The specific items of the BNCT dedicated line and of an additional neutron production station for material science (LENOS) are listed separately.
A few remarks on the table of costs are presented in the following.
The costs of the re-accelerator are for an upgrade of the cryogenic system of the present ALPI, for the reallocation of PIAVE and for the construction of a buncher RFQ and the Charge Breeder.
The costs for the Direct Target stations designed for a beam power of 10kW, are the result of an extremely detailed analysis and of a close comparison with the cost of similar items at existing facilities (e.g. ORNL, TRIUMF, CERN, GANIL) as well as the result of the design and test work performed during 2006.
As for the item "Building and Infrastructures", the updated cost of neutron proof plants, appropriately shielded buildings, accelerator safety and radiation control are considered. The estimation of the cost was done taking as reference facilities with similar characteristics as SPIRAL2 and the ARRONAX project which make use of an IBA C70 cyclotron, a proton driver similar to the SPES one.
Computer control, following our experience and widely shared practice, is added as a 5% addition to the cost of the facilities.
The personnel costs are not included in the table.
It is estimated that the running costs will amount to around 10 M€/year.
On the critical path is the definition of the preliminary project for buildings and infrastructures followed by the authorization to construct.
The project is actually only partially financed and it is waiting for the final approval by the INFN Board.

10. Conclusions

The SPES project is part of the INFN Road Map and it represents the main Nuclear Physics development of the Institute for the next years. It is organized as a wide collaboration among the INFN Divisions, Italian Universities and international Laboratories. The SPES collaboration allows covering all the specific aspects of the project, also those outside the main competences available inside INFN. A strong link and support was established with ISOLDE (CERN, CH) and HRIBF (ORNL, USA). With SPIRAL2 (GANIL, F) there is a collaboration in the frame of LEA (Laboratorio Europeo Associato) which aims to share the technical developments and the scientific goals in the field of Nuclear Physics with exotic beams.
SPES is an up to date project in this field with a very competitive throughout representing a step forward to the European project EURISOL. The relevance of the project is not only related to the Nuclear Physics research but also to Astrophysics and Applied Physics: mainly for Nuclear Medicine, material research and nuclear power energy.
The possibility to operate at the same time the ALPI Superconductive Linac, the high current RFQ and the 2 exit ports Cyclotron give a large improvement to the research capabilities at LNL.

In the following the involved people which collaborate on the SPES design are listed.

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S.Lunardi – INFN Sezione di Padova and Università di Padova
G.Casini– INFN Sezione di Firenze
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Advisory Committee
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"SPES-Executive Summary" is also available on CD and at the web site: http://www.lnl.infn.it/~spes/