PROJECT OF AN ADVANCED ISOL FACILITY FOR EXOTIC BEAMS AT LNL

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Abstract

In the framework of the European program to define a second generation Radioactive Ion Beam facility, LNL are proposing the construction in the next five-seven years of a specialized national facility for RIB originated by fission fragments produced by secondary neutrons. It consists on a two-accelerator ISOL-type facility to provide intense neutron-rich radioactive ion beams of highest quality, in the range of masses between 80 and 160. The conceptual design is based on a high intensity 50 MeV (100 kW) proton linac as driver and on the availability of the heavy-ion accelerator ALPI as post accelerator. The estimated neutron yield is 2 x 10^{14} n/s at 0^0, high enough to satisfy the demand for an advanced RIB facility. An intense R&D program on different items is actually in progress in collaboration with other Laboratories and University groups and is moving in a European context.

1 INTRODUCTION

There exist at a European level strong indications towards a second generation Radioactive Ion Beams (RIB) - so-called "regional" - facility, representing an international laboratory able to carry out leading research in what is universally recognized as a new and promising field of Nuclear Physics. The Legnaro National Laboratories (LNL) intend to take part in all the activities connected with such a "regional facility", promoting initiatives at a national level, which may contribute significantly to the realization of the project.

The Legnaro National Laboratories consider that the design and construction of a regional next generation ISOL-type facility for radioactive ion beams production, within the framework of a European concerted action, is a matter of high priority and a natural extension of their scientific vocation. Moreover, LNL already own a heavy ion accelerator complex, detector systems and infrastructures which could easy be integrated in an advanced ISOL-facility.

The Legnaro National Laboratories are studying the actual construction of a specialized facility for RIB originated by fission fragments produced by secondary neutrons. This facility will be characterized by moderate size, performance and cost and will allow to have intense neutron beams. This may represent an integrating part of the regional facility and a first step towards its realization. Moreover, it will allow to carry out promptly significant experiments and activities in both fundamental and applied Nuclear Physics (medicine, biology, solid state,...). In fact, recently LNL have submitted to INFN a project called SPES (Study and Production of Exotic Species) [1] aimed at the construction of an advanced facility based on the ISOL method for the production and acceleration of neutron-rich exotic beams, with mass ranging from 80 and 160. The program is coordinated at a national level and it extends the collaborations between the INFN sections (LNL, LNS, Napoli, Bari, Bologna) and ENEA-ERG-SIEC already collaborating within the TRASCO-A Project [2] financed by L.95/95, funds of 1996. In addition to that, a network of European and international collaborations has been established. At European level, within the fifth EU framework program LNL participates in RTD joint efforts, which involve large scale facilities and University groups, already active in the present FINA concerted actions and in designing the next generation ISOL facility. Moreover a number of protocols and memorandum of understanding have already been signed (with CEA-IN2P3, ITEP-Moscow, IAE, BINP-Novosibirsk).

In the follow the features of the facility will be described in conceptual terms. This description will be governed by the knowledge of what is now technologically available and/or what is expected to be achieved by technological advances in the next few years. In fact, an important and active R&D program, especially in the neutron conversion target, the target/ion source and charge breeding areas, is an integral part of the full project.

2 THE FACILITY CONCEPT

We propose a two-accelerator ISOL-type facility to provide intense neutron-rich radioactive ion beams of highest quality, in the range of masses between 80 and 160. The proposed production mechanism is the fission induced by fast neutrons in fissile material targets. The fission mechanism has the advantage that very neutron rich radioactive beams can be produced. The conceptual design is based on a high intensity proton linac as driver and on the availability of the heavy-ion accelerator ALPI as post accelerator [3]. The main idea is to use the primary beams to produce, by a converting target, an intense flux (~ 2 x 10^{14} cm^{-2} s^{-1}) of fast neutrons. The use of a converting target partially solves the problems concerning the beam power dissipation and radiation damage in the radioisotope production target/ion source system. The purely nuclear mechanism of energy loss and the long collision length of neutrons allow rather large target thickness to be used for more effective isotope production. The primary accelerator is a sequence of RFQ-ISCL linac which can deliver a 50 MeV proton beam with a power of 100 kW. The RFQ [2] accelerates the beam up to 5 MeV while further acceleration up to 50 MeV is accomplished by the ISCL linac [4]. The facility is planned to be located below ground level to assist in the prompt neutron radiation shielding. The beams delivered by the driver will produce neutrons and subsequently radionuclides by irradiating targets in a well-shielded dedicated area. The radionuclides will be extracted at 20 kV from the target and ionized to the 1+ charge state, charge breeded to obtain a mass over charge ratio of about 10, mass separated, and then sent either directly to an experimental area for research with ion traps, or to the secondary-beam accelerator which will be housed in the existing ALPI building. To fill the ALPI linac with these very low energy beam requires a new accelerating stage (pre-accelerator) up to about 1 MeV/u. The pre-accelerator consists of three low-frequency RFQs similar to the ones of the PIAVE injector [5]. These low-energy secondary beams can be delivered to the experimental area, located in the ALPI building, for low-energy experiments (astrophysics). The further acceleration up to about 7 MeV/u ($^{132}Sn^{13+}$) is accomplished by the ALPI linac and the radioactive beams will be delivered to the existing experimental areas. The capability of the ALPI linac to accelerate stable beams will remain independent of this program, both during construction and operation with radioactive beams.

3 NEUTRON PRODUCTION YIELD AND SECONDARY BEAM INTENSITIES

High energy neutron sources based on high current continuous wave (CW) proton accelerators and thick targets of light nuclei provide the most suitable intensities for the aims of the project. The experimental data on proton induced neutron source reactions were reviewed by Lone [6] and Barschall [7]. The high energy neutrons measured from thick liquid lithium targets exhibit spectral shapes and angular distributions which are suitable for this purpose. The yield of neutrons (per incident proton) with energy above 2 MeV emitted in an angle between 0^0 and 20^0 is about $9.5x10^{-3}$ (n/p) so that an intensity of $1.2x10^{14}$ (n/s) is expected, for 100 kW power in the stopping liquid lithium target. The average energy of the emitted neutron results to be about 20 MeV. In Table 1 are reported the expected beam intensities for a primary proton beam energy of 50 MeV and 100 kW power. The stopping target is liquid lithium and the production target is uranium carbide with a thickness of 300 gcm^{-2}. The intensity evaluations are done by using the experimental fission yield values taken from Ref. [8].

Table 1: Expected beam intensities for a production proton beam of 50 MeV and 100 kW power. The overall efficiency values are taken from Ref. [9]. * Value taken from Ref. [10].

Isotope	Half-life	Prd.Rat [At./pμ]	Overall Eff. [%]	Beam Int. [Atoms/s]
Zn^{72}	46 h	1.3 x 10^3	8	5.2 x 10^5
Zn^{78}	1.5 s	1.2 x 10^6	0.48	2.9 x 10^7
Kr^{91}	8.6 s	9.4 x 10^8	29	1.4 x 10^{12}
Kr^{94}	0.2 s	2.6 x 10^8	6.4	8.3 x 10^{10}
Rb^{97}	0.17s	3.2 x 10^7	11	1.7 x 10^{10}
Cd^{131}	50 ms	10^2	0.25*	10^3
Sn^{132}	40 s	6.7 x 10^8	2.4	8 x 10^{10}
Sn^{138}	87 ms	8 x 10^2	0.37*	1.5 x 10^4
Xe^{142}	1.22 s	5.5 x 10^8	26	7 x 10^{11}
Xe^{144}	1.2 s	4.4 x 10^7	26	5.7 x 10^{10}
Cs^{144}	1 s	6.3 x 10^8	38	1.2 x 10^{12}

4 R&D FOR THE SPES PROGRAM

During the development of the conceptual design for the SPES facility, numerous areas in which additional research and development (R&D) seemed appropriated have been identified. These areas are briefly described below. The R&D on the different items actually in progress is done in collaboration with other Laboratories and University groups and is moving in a European context.

The driver. The main accelerator has been designed in the framework of the TRASCO project, the INFN-ENEA feasibility study for a waste transmutation Accelerator Driven System [2]. For the TRASCO project the proton linac consists of a CW RFQ (Continuous Wave Radio Frequency Quadrupole) up to 5 MeV, followed by an ISCL (Independently phased Superconducting Cavity Linac) [4] up to 100 MeV. For the SPES project a similar driver is proposed with 50 MeV energy and 100 kW beam power.

Neutron production target. It was mentioned above that a lithium target-converter serves as an efficient neutron source for isotope production by fission in the secondary production target. Because of the low melting temperature of lithium (179^0C) and the low thermal conductivity (45 W/m^{0}C) metal targets are not stable at high beam power. The removal of the huge heat (100 kW) from the target imposes a big challenge on the target design. However, up to megawatt beam power, a fast flowing lithium jet target provides an attractive alternative to other techniques. Considerable experience already exists of the long term operation of liquid lithium systems [11].

Target/ion source. In order to investigate on the neutron-rich nuclei produced by neutron-induced fission of uranium, an isotope separator for on-line operation coupled to the 7 MV CN van de Graaff accelerator has been installed at LNL. The idea is to produce neutrons by bombarding thick beryllium targets with deuterons accelerated up to an energy of 7 MeV and current of 3 μA. The expected total neutron yield at 7 MeV deuteron energy is $5x10^9$ neutrons/sr/μA at 0^0, with an average energy $<E_n>$ = 3.2 MeV. The on-line test stand for study the production yields, the release efficiencies, the delay times in the production targets and for testing the ion source efficiencies and emittances. A high-temperature integrated target-ion-source system has been designed for the on-line mass separator. This system includes, other than the target, a 1+ charge state surface ionization source operating at 20 kV. The expected production rates at the target level for several different isotopes is estimate ranging in between $10^4 – 10^6$ atoms/s.

Charge breeding. To accelerate radioactive beams efficiently, ions charge greater than +1 may be advantageous. Efficient production of such ions would also reduce the cost of the acceleration stages. The Trapped Ion Source (TIS) [12] is a new type of source capable, in principle, of producing very highly charged ions and, at the same time, it is a radio frequency quadrupole linear trap suitable to study the interaction of the trapped ions with electrons, high-energy particles or laser beams. The main new feature of TIS, with respect to an EBIS (or EBIT), is the adding of radial ion confinement of the rf quadrupoles to the potential well of the electron beam space charge. In this way by adding to the rf field a continuous quadrupole field it is possible to select the ion type to be contained in the pseudo-potential well (as is done in a common mass spectrometers). In meanwhile, the slow electrons, generated form successive ionizations, are swept away because the rf period is much less than the electron transit time of the quadrupole field.

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