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Abstract

The Production of neutron-rich radioactive nuclei through fission is currently prime of research interest for the future radioactive beam facilities. For example in the EURISOL[1] project, photo-fission and fast neutron induced fission are proposed. The photo-fission cross-section for ^{238}U is about 0.16 barn (against 1.6 barn for fast neutrons of 40 MeV) but the conversion electrons/gammas is much more efficient than that of deuterons/neutrons. It was necessary, to test this new method of production, to carry out, in equivalent conditions, an experiment of the type PARRNe-1 using a 50 MeV electron beam. In April 2001, production of fission fragments induced by gammas proved to be successful. Bremsstrahlung gamma rays were produced by the few nA-50 MeV electron beam delivered by the CERN LEP Injector Linac (LIL). This promising alternative has stimulated the study of a new experimental area at IPNO based on an electron Linac close to the Tandem, through a collaboration with LAL and CERN PS groups

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The Production of neutron-rich radioactive nuclei through fission is currently prime of research interest for the future radioactive beam facilities. For example in the EURISOL[1] project, photo-fission and fast neutron induced fission are proposed. The photo-fission cross-section for ^{238}U is about 0.16 barn (against 1.6 barn for fast neutrons of 40 MeV) but the conversion electrons/gammas is much more efficient than that of deuterons/neutrons. It was necessary, to test this new method of production, to carry out, in equivalent conditions, an experiment of the type PARRNe-1 using a 50 MeV electron beam. In April 2001, production of fission fragments induced by gammas proved to be successful. Bremsstrahlung gamma rays were produced by the few nA-50 MeV electron beam delivered by the CERN LEP Injector Linac (LIL). This promising alternative has stimulated the study of a new experimental area at IPNO based on an electron Linac close to the Tandem, through a collaboration with LAL and CERN PS groups.

1 INTRODUCTION

The availability of intense neutron-rich ion-beams will open new perspectives in the study of nuclei very far away from the valley of stability. It would allow one to investigate the behaviour of nuclear matter under extreme conditions [1,2]. Several laboratories have concentrated their efforts in studies aimed at producing beams intense enough for the next generation of experiments (SPIRAL II and EURISOL). To produce such beams, a considerable R&D effort is required. Uranium fission is a very powerful mechanism to produce such radioactive beams. A substantial part of the PARRNe program (**P**roduction d'**A**tomes **R**adioactifs **R**iches en **Ne**utrons) at the IPN Orsay is dedicated to the development of n-rich isotope beams by the ISOL (Isotope Separator On-Line) method. To produce the n-rich isotopes, fission induced by fast neutrons in a thick ^{238}U target has been investigated [3]. Yields of radioactive noble gases have been measured for different deuteron energies with the so called PARRNe-1 set-up in the framework of the European RTD program SPIRAL-II. The goal of the PARRNe R&D is the determination of the optimum conditions for the production of neutron rich atoms by the ^{238}U fission. An ISOL device PARRNe2 has been developed to carry out various R&D work [4].

2 INVESTIGATION OF PHOTO-FISSION PRODUCTION MODE

In order to probe neutron rich radioactive noble gases produced by photo-fission, a PARRNe-1 experiment has been carried out at CERN. The incident electron beam of 50 MeV was delivered by the LIL machine. This experiment allowed us to test the production of noble gases by photo-fission under the same conditions as during the previous PARRNe-1 experiments using fast neutrons. The incident electrons are slowed down in a W converter or directly in the target, generating Bremsstrahlung γ-rays which may induce fission. In the photo-fission method proposed by Diamond [5], nuclei are excited by photons at the Giant Dipolar Resonance (GDR). It is well known that the fission cross section at the GDR energy is 0.16 barn for 238U (against 1.6 barn for 40 MeV neutrons induced fission) but the electrons/γ photons conversion efficiency is much more significant than that of deuterons/neutrons. Estimations indicate that $3x10^{13}$ fissions/s could be produced in an optimal ^{238}U target using a 100 kW beam of 30 MeV electrons which is about the optimum energy for this production mechanism.

PARRNe-1 has been designed to be compact and portable to enable its installation at various accelerators. The search of the optimal energy of the deuterons was done by installing this set-up successively at IPN Orsay (20 MeV) [6], at CRC Louvain La Neuve (50 MeV) and at KVI Groningen (80 and 130 MeV) [7]. In the following we will concentrate on the photo-fission experiment. The PARRNe-1 set up consists of measuring the activity of produced radioactive noble gases by trapping them on a cold finger (13°K) in front of which is placed a Germanium detector (figure1). The cold finger is connected to the target by an 8 meter long tube at room temperature. This device allows one to shield the detection system from the irradiation point. The target is composed of 67 disks of ^{238}UCx of 14 mm diameter and 1mm thickness. The contained ^{238}U quantity in the target is 23 g. The target is heated to 2200 °C within a graphite container which is placed inside a graphite oven. All other elements produced are condensed at the entrance of the long tube.

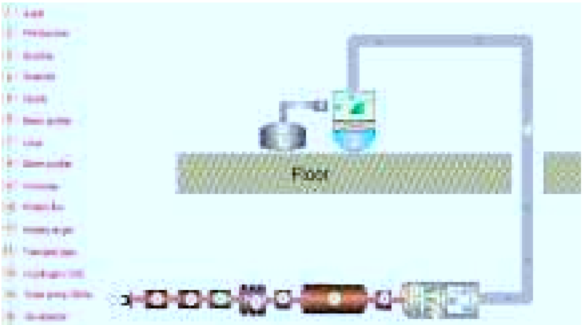

Figure 1: PARRNe-1 experimental set-up at LIL (LEP Injector Linac)

The on-line production of Krypton and Xenon has been performed. Measurements were carried out in various configurations [8]. Some of them have been done with a converter placed at 8 cm and then 4 cm from the target, other measurements have been done without converter (the target was bombarded directly with electrons). The measurements have been performed during 10 cycles in order to get enough statistics. Each cycle consists of irradiating the target during 1mn and collecting the resulting activity during a longer time. The acquisition time is long enough for the decay of nuclei trapped by the cryo-finger.

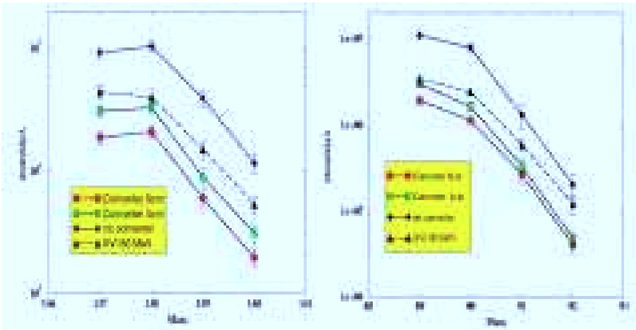

Figure 2: Production rates obtained for Kr and Xe isotopes at LIL in different configurations compared with the results obtained at KVI using 80 MeV deuterons. The data are normalized as production per second of 1 µA.

The results obtained for Xe and Kr are presented in figure 2. The gain of 1.5 when the distance converter-target is reduced from 8 to 4 cm indicates how broad is the angular distribution of the incident γ flux. The gain becomes higher when the target is irradiated directly (without converter), the production increases by almost a factor 4. The comparison of the production when the target is hit directly by electrons to that obtained at KVI using 80 MeV deuterons, shows a gain of a factor 2.5 in favor of photo-fission. The extrapolation of the obtained results indicates that the use of a 50 MeV electron beam of 10 µA, would allow a gain in production by a factor of 100 in comparison with PARRNe-2 results (using a 26 MeV deuteron beam of 1 µA). On the one hand the installation of an electron accelerator close to the PARRNe-2 device at Orsay would offer the possibility of providing for example 3.5×10^7 ^{132}Sn /s and 2×10^5 ^{78}Zn /s. On the other hand, the lower cost of an electron driver and the ease with which it is possible to obtain intense primary beams, make this option very attractive. After the success of the photo-fission experiment, the CERN scientific authorities interested in our project have decided to offer us the LIL front end [9] to be installed in the experimental area of the Tandem at Orsay: ALTO project (Accélérateur Linéaire auprès du Tandem d'Orsay). A substantial physics case has been elaborated [10] including β and γ decay measurements of very exotic nuclei, mass measurements, laser spectroscopy measurements and "in beam" experiments.

3 LINAC DESCRIPTION

The schematic lay-out (figure 3) shows an overall view of the main components of ALTO. The required characteristics of the linac for photofission are the following:

RF frequency:	2998.55 MHz
Repetition rate:	100 Hz
Gun peak current:	50 mA
Output averaged current:	10 µA
Beam pulse length:	2µs
Output energy:	50 MeV
Energy spread:	< 5%

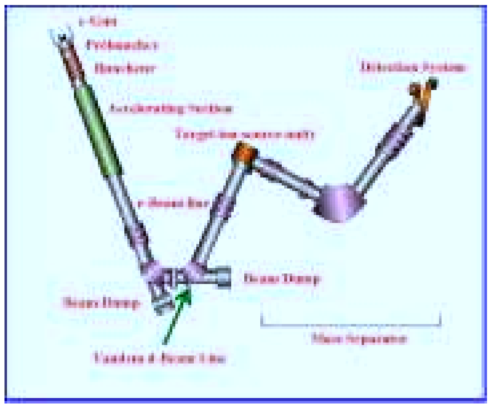

Figure 3: Schematic layout of ALTO

3.1 Injection system

The injector consists of a 90 kV thermionic gun, a pre-buncher, and a buncher. The triode gun operating at 100 Hz, produces 2 µs long pulses of 50 mA peak current. The pre-buncher is a 15 mm long cavity working in TM_{010} standing wave mode at 3 GHz. This cavity produces a energy modulation of ± 20 kV. The buncher is a tri-periodic structure working in standing wave mode at 3 GHz. This cavity provides 14 ps bunches and an output energy of 4 MeV. The cavity structure is surrounded by a solenoid producing a 0.2 T magnetic field in order to improve the beam transmission. For the transverse focusing of the beam, three solenoids are installed downstream of the gun.

3.2 Accelerating section

The accelerating section consists of disc-loaded wave guides working in the $2\pi/3$ TW mode with quasi-constant field gradient [11]. The section is composed of 135 elementary cells assembled by silver diffusion type brazing. The whole is placed inside a stainless-steel vacuum envelope. This section provides an energy gain of 46 MeV for only 11 MW input RF power. For the beam matching to the section, one solenoid and one quadrupole triplet are inserted between the buncher and the accelerating cavity. Recently, transmission tests of a similar section have been performed at CLIO [12]. They have shown the same transmission through the strucure with and without the surrounding solenoid field.

3.2 RF System

The system is based on the use of a Thalès klystron (TH2100) and a modulator from LAL (figure 4). The 3 GHz klystron which has 5 integrated cavities delivers a 4.5 µs long RF pulse and provides a peak power of 35 MW. The average power is about 17 kW. The linac operation requires only 20 MW, therefore a fraction of the nominal power (30 W) delivered by the system would be used to test new RF components designed by the group in the framework of accelerator R&D. The RF power is distributed by a waveguide network (WR 284) under SF_6 gas as dielectric medium at a pressure lower than 6 bar. The power and the phase at the pre-buncher and the buncher are adjusted by inserting attenuators and phase shifters .

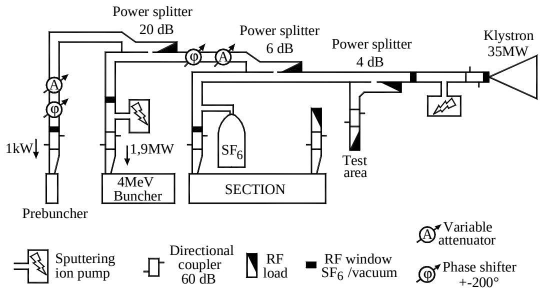

Figure 4: Power RF network

3.3 The Beamline

The designed beam line consists of two 65° dipole magnets (R=0.4 m) and seven magnetic quadrupoles (figure 5). The first quadrupole triplet placed behind the accelerating section allows the control of the beam envelope at the entrance of the first dipole. To achieve the achromaticity of the deviation, a quadrupole is placed between the two dipoles. The beam dimension is adjusted on the PARRNe target using the last quadrupole triplet. The beamline will be equipped with beam diagnostics: measurement of current, beam position, energy and energy spread.

3.4 Vacuum System

The vacuum system is composed of six 240 l/s sputter ion pumps. At the entrance of the RF cavities the network is pumped by two 70 l/s sputter ion pumps. The linac is maintained at a residual pressure lower than 10^{-7} mbar. The upper pressure limit in the gun is $2x10^{-8}$ mbar. The whole vacuum system is controlled by a Siemens automat.

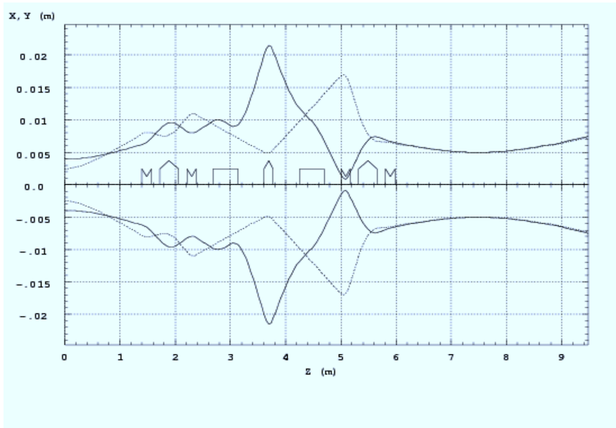

Figure 5: Beam transport calculations

4 CONCLUSION

The installation cost of ALTO is estimated to be 1.4 M€ without including the cost of the LIL front end (from CERN), the RF system (from LAL), and all the infrastructure and manpower (from IPNO). After acceptance of the financial plan before the end of 2002, the ALTO project schedule will be extended to a maximum period of 18 months. The use of ALTO will open experimental applications in different fields such as biology, biochemistry, industry, accelerator R&D for the test of newly developed cavities and diagnostic instrumentation.

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