MUNES A COMPACT NEUTRON SOURCE FOR BNCT AND RADIOACTIVE WASTES CHARACTERIZATION

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Abstract

At INFN LNL (Legnaro Italy) it has been built a high intensity Radio Frequency Quadrupole (RFQ) structure, able to produce a 5 MeV proton beam of 30 mA. Coupled with a Be target such a beam can generate a neutron flux of 10^{14} n/s, with a spectrum centred in the MeV region (that has been recently characterized in detail at LNL accelerators). This neutron flux can be moderated to generate a thermal or epithermal source for BNCT with very little contamination of energetic form energetic neutron and gamma.

Since the approval of MUNES project (in 2012) the high technology issues related to a compact neutron source to be installed in a Hospital environment have been faced. In particular for the powering of the accelerating structure an innovative system, completely based on solid state amplifiers, has been developed and ordered to industry. An outline of MUNES design and the status of the project will be given in the paper.

INTRODUCTION

New neutron sources are being developed for various applications (test of materials for fusion reactors, experimental oncological treatments, characterization of nuclear wastes…), based on high intensity "low energy" (up to 40 MeV) proton or deuteron linear accelerators. This kind of sources has recognized advantages respect to reactors and spallation sources for these applications.

The project MUNES (Multidisciplinary Neutron Source), aiming at the realization of an intense source of thermal-epithermal neutrons for Boron Neutron Capture Therapy (BNCT) and for the characterization of nuclear wastes, has been launched during 2012. Such neutron source is based on a high intensity linear accelerator under realization at Legnaro National Laboratory.

The accelerator is a Radio Frequency Quadrupole able to accelerate 30 mA of protons up to 5 MeV. The RFQ was developed in the last years in the framework of TRASCO project (see Fig.1). For BNCT application this CW source promises unique performances in terms of neutron flux and spectra (very low gamma and fast neutrons components) as needed for a successful therapy. For the characterization of waste barrels (mainly for the detection of very low plutonium content) a pulsed neutron beam with high pick intensity shall be used; this approach should allow to improve dramatically (at least two order of magnitude) the sensitivity to Pu content respect to the present devices based on D-T sealed tubes with an important economic impact on nuclear waste cycle.

The proposal of a neutrons source based on TRASCO RFQ for these applications has a quite long history as SPES-BNCT project [1], in close collaboration with IOV (Istituto Oncologico Veneto) and other institutions. More recently, it has been approved a trilateral collaboration between INFN, University of Pavia and SOGIN (public company for nuclear sites decommissioning) for the development of such a neutron facility at Pavia. Finally with the so-called "Progetti Premiali", the project MUNES has been selected by MIUR and funded with 5 M€, that allows a substantial step forward in the realization of the accelerator high technology part. Table 1 summarizes the main parameters of MUNES.

Table 1: MUNES main parameters

Ion source	TRIPS	Proton energy 80 keV
Accelerator type	RFQ	Radio Freq. Quadrupole
Final energy	5 MeV	
Beam current	30 mA	accelerated
Duty cycle	CW	Continous Wave
Neutron	Beryllium	Water cooled 150 kW
Neutron source intensity	~10^{14} s^{-1}	entire solid angle, Ave. neutron energy 1.2MeV
RF power	1.0 MW	
Electrical power	5 MVA	

Figure 1: TRASCO RFQ modules.

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THERAPEUTIC NEUTRON BEAM PRODUCTION

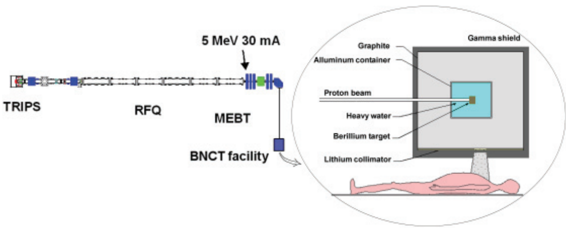

Figure 2: BNCT treatment scheme

In the recent ICT16 congress [2] in Finland emphasis has been given to the necessity of accelerator based facility for BNCT treatment, with both thermal and epithermal neutron (surface and deep tumours). In particular in Japan multiple projects based on different technologies and accelerator-target combinations have been funded and are in construction.

In Fig. 2 the schematic lay-out of our accelerator based BNCT is shown. Our choice of a water cooled Be target and low energy proton beam is optimal for many points of view: respect to Li the design can be more reliable thanks to better mechanical and thermal properties (1278 deg C vs 180 deg C melting point, 201 W/mK vs 85 W/mK thermal conductivity), avoids production of ^{7}Be and tritium and conventional safety issues related to liquid lithium.

To keep low the proton energy is very important since it determines a neutron spectrum without high energy tails (Fig. 3-left). This is extremely important because fast neutrons, determining damage without therapeutic effect, need thermalization that would require strong increase in the moderator dimensions. On the other hand the production increases with energy (Fig 3-right), and therefore at 5 MeV a larger current is needed to reach the neutron production goal (reasonable treatment duration). For this reason, with a CW RFQ, that has a uniquely high beam current, we can use a parameter set inaccessible to pulsed linacs or cyclotrons.

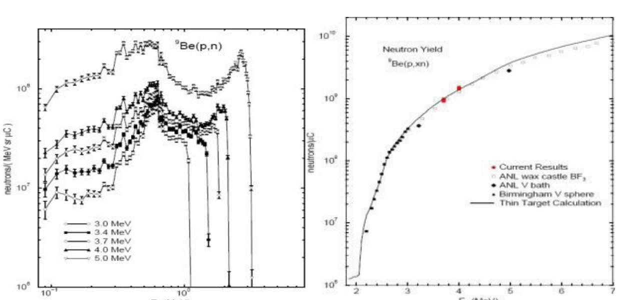

Figure 3: Neutron spectra with 5 MeV incident proton energy on Be (left). Neutron production from a thick Be target as a function of incident proton energy (right).

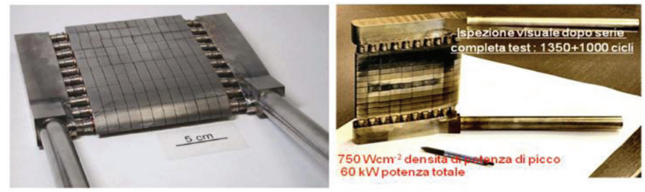

Figure 4: Beryllium target prototype.

In the past years a prototype target (Fig.4) was built and tested with electrons to the nominal power density (equivalent to 150 kW total) and under nominal neutron flux in an experimental nuclear reactor. Target tests with proton were started but the assessment of target duration against blistering (gas permeability is extremely low, nine order of magnitude lower than average materials) was not completed.

A new target design, able to keep the Bragg peak out of the Be layer, has been developed; the first prototype of a 65 um thick Be foil brazed on copper brick has been ordered.

The BNCT treatment station will be equipped with a converter target in beryllium and with a neutron shaping assembly (nuclear graphite, heavy water and other materials) for neutrons spectrum moderation. A low contamination from fast neutrons and gammas is fundamental for the success of the therapy (design and Montecarlo simulation in Fig. 5) [3]. The design of an epithermal moderator is also going on as part of MUNES project.

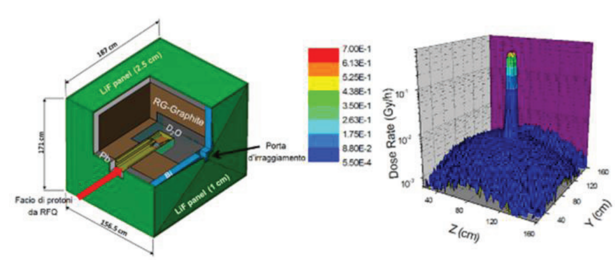

Figure 5: Design of the thermal BNCT moderator (left) and thermal dose at the irradiation port (right).

THE ACCELERATOR.

As mentioned this neutron source needs a high intensity CW accelerator.

The accelerator status is the following: the ion source TRIPs (RF off resonance) has produced the nominal beam of 60 mA.

The TRASCO RFQ [4] cavity was tested to the nominal field and duty cycle [5] (up to 2.2 E_{kp}, 80 kW/m, 100% duty cycle). Many components of cooling, beam instrumentation, control system have been developed in synergy with IFMIF project. The cooling system skid is in construction.

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Figure 6: TRASCO RFQ during high power tests at CEA Saclay.

A very important point of MUNES development is the RF system: the RFQ was originally built to be operated by one of the CW klystrons (1.3 MW) used at CERN for LEP collider. The test of our RFQ at CEA Saclay was indeed done with one of such RF sources. The test was very successful (Fig.6), but, in relation to a future installation in a hospital, it put in evidence many safety, reliability and running cost issues (mainly related to the presence of high voltages and of a single high power electron beam).

Nowadays it is possible to develop a solid state amplifier of 125 kW (Fig. 7), and feed the RFQ with eight of these systems in parallel (one for each input coupler). This solution, developed with Italian industry, has many advantages and is particularly well suited for a possible installation of the accelerator in a hospital environment. The first five RF modules have been ordered to the company INTECH.

It should be finally noticed that the possible construction of a new RFQ for this application would be straightforward also thanks to our experience with IFMIF EVEDA RFQ construction [6].

Figure 7: Schematic lay out of one of the eight 125 kW solid state amplifiers, developed in three standard racks.

DIFFERENT APPLICATIONS

Part of the management of radioactive waste produced in Italy by industrial research and medical processes is the so called Passive/Active Waste Assay System (PANWAS) [7]. It uses neutron differential die-away technique to quantify the fissile content (^{235}U, ^{239}Pu etc.)

Presently it uses a pulsed neutron source (sealed D-T tube, 10^6 n/pulse in 10 us 100 Hz) and He3 neutron detector. With MUNES RFQ (10^9 n/pulse in 10 us 100 Hz, neutron average energy 1.2 MeV against 14) the sensitivity to Pu contamination can be dramatically improved. This application is pulsed (less demanding for the accelerator), but specific issues for the integration of the measuring point have to be solved.

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