HIGH POWER NEUTRON CONVERTER FOR LOW ENERGY PROTON/DEUTERON BEAMS: PRESENT STATUS*

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Abstract

In BINP, Russia, the high temperature neutron target for SPES project (INFN-LNL, Italy) is proposed. The target is designed to produce up to 10^{14} neutron per second within the energy range of several MeV under irradiation by proton/deuteron beam of power up to 200 kW. By now, the target prototype is successfully tested. The development of liquid metal driving system and target general design is started. This paper describes the design of the target and the target prototype as well as the results of prototype tests under high-power electron beam.

Special attention is paid to the carbon material with high content of ^{13}C isotope. The material is produced in accordance with the original technology and is used for manufacturing the converter irradiated with the proton beam.

INTRODUCTION

In the framework of the European program, to define a second generation Radioactive Ion Beam (RIB) facility, the Legnaro National Laboratories (LNL) are proposing the construction in the next years of a specialized national facility for RIB originated by fission fragments produced by fast neutrons (SPES) [1]. Protons/deuterons of 40 MeV and 150 kW will produce in a converter about 10^{14} neutrons per second centered at around 14 MeV that will induce fission in a suitable fissile target, with the aim of 10^{13} fission per second at least.

The neutron energy distribution, the target size and its constituents are the most important parameters to be investigated in order to maximize the efficiency for RIB production. A few different methods for producing fast neutrons and their induced fissions following the (p,xn) or (d,xn) reactions on different materials were investigated.

Designing the SPES facility, simulations of neutron spectra for several beam converter materials/configurations have been performed with the MCNPx [2] and the PRIZMA [3] codes. Furthermore, the isotopic distributions are evaluated combining the MCNPx with the code SP-FISPACT2001 [4] that allows the neutron transport below 20 MeV. The simulations performed were compared with experimental angular distributions measured at energies of 20, 40, 50 and 90 MeV for ^{12}C, ^{13}C and beryllium converters.

Results of simulations show the difference of neutron yield between different converter material are not critical, optimal target construction is more important. Calculated neutron angle-energy distributions allowed to estimate the different isotopes production and radiation shielding, to propose and optimize the full target system assemblage (see fig.1).

The design of the converter and its prototype and the results of the prototype tests are discussed in detail in the following paper.

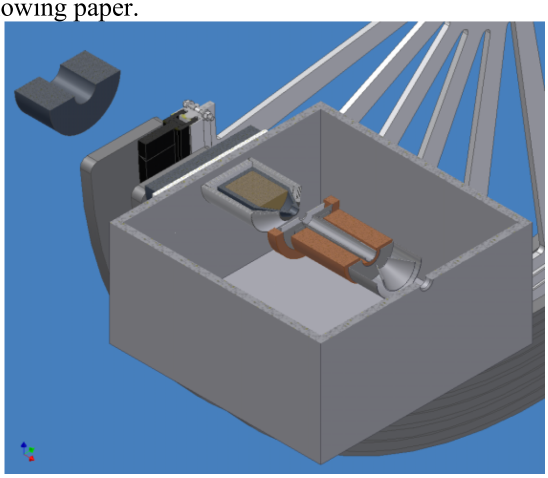

Figure 1: Layout of the SPES target system. Left to right: protecting collimator, neutron converter inside the cooling panels, fission target, ion source.

CONVERTERS AND PROTOTYPE DESIGN

The proposed target design [5] comprises the carbon converter assembled with plates, which are mounted on rotating metal disk (see fig.1). The converter material considered is ^{13}C (for proton beam) and natural carbon (for deuteron beam), both under graphite form with thickness of 10 mm, suitable to stop full beam inside it. The diameters of the wheel and of the rotating shaft are close to 100 cm and 5 cm, respectively. The thermal power deposited in the converter material is dissipated only by thermal radiation. Heat removal from vacuum chamber is carried out by water circulating inside aluminum cooling channels fixed to the chamber's walls. Before the converter a collimator acts as a beam position monitor. Beyond the converter, a graphite plate serves to survey and monitoring eventual damages of the converter and, at the same time, protects the vacuum chamber from primary beam.

The converter prototype is described in detail in paper [6]. It is scaled to 1/3 of the real power (50 kW) by reducing its dimensions and limited to 20 MeV equivalent proton beam energy to match the energy and power of the electron accelerator used to perform experimental tests. All construction is assembled inside the special cooled vacuum chamber. The rotation of prototype is carried out by an electrical motor by means of a ferromagnetic rotary feedthrough.

The most important thing is to investigate the converter parameters as follows: maximum operating temperature and thermo-mechanical stress distributions inside the converter itself; mechanical stress due to the rotation is far less than thermal one. During regular operation converter can reach the temperature up to 2000^0C for effective cooling, and temperature gradients up to 100^0C/mm (see fig.2).

Main purposes of the tests were the examinations of the basic physical and technical solutions proposed for the target:

- To clear up the possibility of converter design to dissipate the beam power, and its reliability;
- To test the cooling channels aimed to accept and remove the heat power;
- To check up the calculations of prototype operation conditions;
- To check up the converter made of 13C-based material under the regular operational conditions.

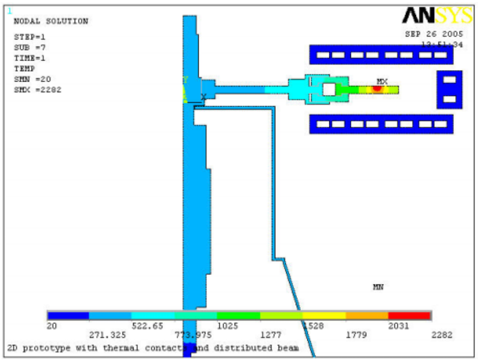

Figure 2 : Temperature distribution (°C) of prototype in regular regime as calculated by ANSYS code.

^{13}C BASED MATERIAL

The material with high content of ^{13}C isotope is not commercially available. In the framework of our project the development of this material was initiated in NIIGrafit, Moscow. Technology is based on the process of MPG-brand graphites production: crushing and sizing of the ^{13}C powder; mixing the components with the phenolformaldegid resin (binder) and urotropin (catalyst); compacting, burning and graphitization. Unfortunately, a few quantity of ^{13}C powder does not permit to perform complex investigation of material properties, but we can obtain material close to industrial graphites (see tab.1). This material stands any mechanical treatment.

Table 1: properties of the ^{13}C-based carbon material.

Properties	1.23 g/cm^3	1.45 g/cm^3
Compression strength, $\sigma_{compr.}$, MPa	29.2	62.6
Heat conductivity at 25°C, λ, W/m ·K	8.5	15.2
Linear heat expansion factor, α, 1/deg.	$3.8\cdot10^{-6}$	$4.3\cdot10^{-6}$
Specific electrical resistance, ρ, μOhm ·m	78.3	51.5

TESTS OF PROTOTYPE

Test of prototype includes the distributed volume heating of prototype converter by the high power electron beam of ELV-6 accelerator [7] with energy 1.4 MeV, diameter over 7 mm, power up to 70 kW. View of prototype installation is shown on the fig.3. During experiment the beam position, current and effective size (by the linear scanning along the prototype diameter) were controlled. The main measured parameters were: graphite converter temperature distribution, temperatures of the metal parts of prototype, heat power accepted by the cooling channels, beam and rotation parameters.

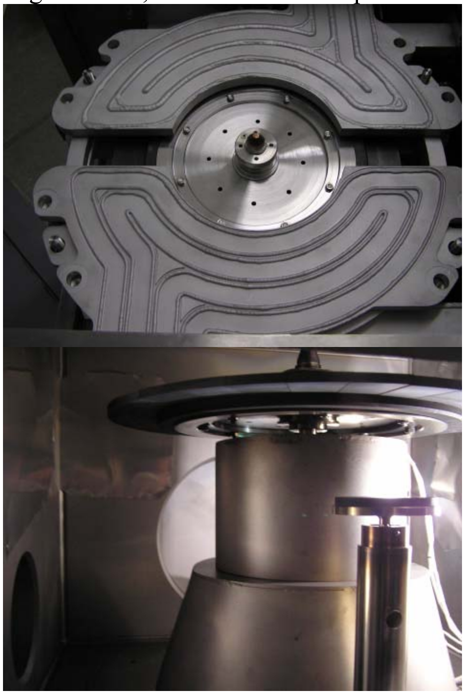

Figure 3 : View of prototype.

The main experimental results are:

- Temperature distribution over the converter's plates under different beam power (20 to 70 kW) and size (7 to 26 mm) corresponds to calculated one;
- Temperatures of the metal elements in the stable regular regime are in good agreement with calculations;
- Total beam power is successfully accepted by the cooling channels within the accuracy of the measurements;
- The assembly with the usual graphite is successfully stood under regular (50 kW power and 8 mm of beam size) regime for more than 70 h, and short time under high power (70 kW, 8 mm) regime;
- The assembly with the 13C-based material is successfully tested under regular (50 kW, 8 mm) regime;

- Studies of carbon materials before and after test did not observe any changes of its structures and properties;
- Prototype operating parameters during the tests were stable and repeatable.

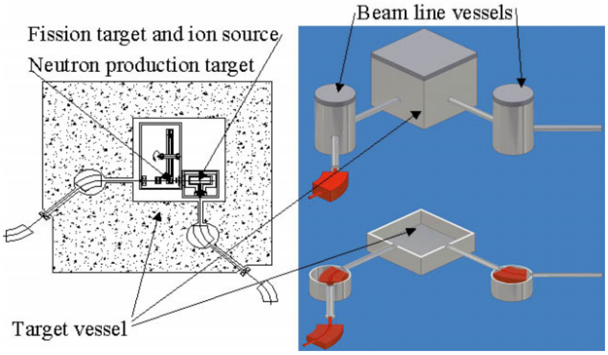

Figure 4 : Schematic view of target area vacuum chamber design.

CONCLUSION

Nowadays the performed R&D represents efficiency of proposed decisions for neutron target:

- Construction of the target was produced and tested with the high-power electron beam;
- New experimental 13C based material was created and tested;
- Neutron angle-energy distribution and radionuclides production were calculated, biological shielding was estimated.

Next steps of the target are started. It is: .

- ***Design of the target system as the single complete unit***. The basic principles arise from the radiation safety: the neutron target, the fission target and the ion source are mounted on common concrete foundation inside large stainless steel vacuum chamber; bending magnets are desired for both beams in order to stop the direct neutron flux coming through beam line aperture; neutron production target and fission target with ion source must be separated one from the other, the space between the neutron production target and the fission target should not exceed 50 mm; replacement of units must be done with the remote handling.
- ***Development of the target rotation driving system.*** Hard operating conditions (high temperature, vacuum, extremely high radiation) do not allow the use of conventional mechanical units. Of possible variants is the use of liquid metal driving system. The main elements of the system are liquid metal pump and the reverse to it liquid metal motor, liquid metal sliding bearings. This approach is under the test now in Budker INP (liquid lead positron production target development in the framework of ILC collaboration). Cogwheel pump for liquid lead was successfully tested at BINP for more than 10000 h in continuous regime.

Figure 5 : The parts of liquid lead cogwheel pump.

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