A Project for High Fluence 14 MeV Neutron Source

Mario Pillon[1]*, Maurizio Angelone*[1]*, Aldo Pizzuto*[1]*, Antonino Pietropaolo*[1]
[1]Associazione ENEA-EURATOM Sulla Fusione, ENEA C.R. Frascati, via E. Fermi, 45,
00044 Frascati (Rome) Italy

Abstract

The international community agrees on the importance to build a large facility devoted to test and validate materials to be used in harsh neutron environments. Such a facility, proposed by ENEA, reconsiders a previous study known as “Sorgentina” but takes into account new technological development so far attained. The “New Sorgentina” Fusion Source (NSFS) project is based upon an intense D-T 14 MeV neutron source achievable with T and D ion beams impinging on 2 m radius rotating targets. NSFS produces about $1\text{x}10^{13}$ n cm^{-2} s^{-1} over about 50 cm^3. The NSFS facility will use the ion source and accelerating system technology developed for the Positive Ion Injectors (PII) used to heat the plasma in the fusion experiments,. NSFS, to be intended as an European facility, may be realized in a few years, once provided a preliminary technological program devote to study the operation of the ion source in continuous mode, target heat loading/removal, target and tritium handling, inventory as well as site licensing. In this contribution, the main characteristics of NSFS project will be presented.

1 Introduction

In the context of the development of future fusion machines, such as DEMO, the availability of a intense 14 MeV neutrons source is of paramount importance to address important issues, e.g. verify the influence of nuclear transmutation on the electric characteristics of ceramic insulators and window materials, experimentally select low activation materials, thus avoiding the uncertainties of numerical calculations, carry out basic studies on neutron damage to materials. In this respect, the feasibility study of the intense 14 MeV source named “The New Sorgentina Fusion Source (NSFS)” is a necessary step toward its full design and realization to serve as a large scale facility for the fusion community.

2 Performances and main feature of NSFS

The performances and main features of NSFS rely on those already stated at the European Workshop on the Requirements of a High-Energy Neutron Source for Fusion Materials Testing and Development held in Rome from 20 - 22 October 1988 [1], where the preliminary study of a single-target high flux fusion source was discussed. The performances were determined as follows: A 14-MeV neutron flux production, $\geq 10^{13}$ cm^{-2} s^{-1} in a volume (for irradiation) ≤ 0.5 dm^3, with a low flux gradient. It must also be possible to carry out simple experiments on materials during irradiation (e.g., heating and cooling of specimens). With the minimum flux required, specimen damage would be equal to 2 dpa over roughly a year's continuous irradiation. The main features should be neutron production with D-T reaction by irradiating a solid target containing tritium, with deuterium ions accelerated to 100-600 keV. Target with high heat dissipation capability, e.g., water-cooled rotating disk made of copper alloy with Ti, Y, or Er coating loaded with T; increased target lifetime against T-loss, e.g., by using a mixed beam (D+T) and thereby continuously reloading the target. The technological feasibility of the above features has partly been demonstrated, and they have been proposed with the aim of constructing Sorgentina possibly within a short period of time , say 3-4 years, as many of these features are already typical of the Rotating Target Neutron Source (RTNS II) [2], that reached a maximum neutron intensity of about 10^{13} s^{-1} As a comparison, the intensity of the NSFS can be two orders of magnitude higher, in the order of 10^{15} s^{-1}. A neutron source that is based on the D-T fusion reaction basically consists of a vacuum vessel containing a T-saturated metal target, a D-ion source, and an electrostatic accelerator. The deuterium ions produced by the source are accelerated to energies of 100 - 600 keV and then hit the target. Here, a small fraction ($8x10^{-5}$ n/deuteron) produces the 14-MeV neutrons through the $T(d,n)^4He$ reaction, while the largest fraction is slowed down by collisions, without giving rise to nuclear reactions, and releases all its energy to the target ($2.5x10^3$ MeV/neutron). Under ion irradiation, the target releases tritium, and the neutron yield decreases with time. When the neutron yield is reduced a great deal, the target is replaced by another saturated with T. NSFS should have a rotating water-cooled target with a good capability for heat dissipation and a mixed D+T ion beam to reload the target with tritium and thus maintain the neutron yield constant for as long as possible. The conditions to insure this fact is to maintain the surface temperature of the target below about 300°C otherwise the deuterium and the tritium loaded by the impinging beams are released at a rate higher then the loading rate [3].

2.1 Consideration on the feasibility study of NSFS

The NSFS project is based upon two intense D-T 14 MeV rotating targets facing each-other. Two beams of 160 keV, 25A each provide 50-50% Deuterons and Tritons on a 2 m radius rotating target. Deuterium and Tritium are implanted during the beams bombardment on a Titanium layer covering the rotating targets. The Titanium layer, spattered by the beams bombardment, is continuous reformed using a Titanium sputtering source. Figure 1 shows a schematic of the target station.

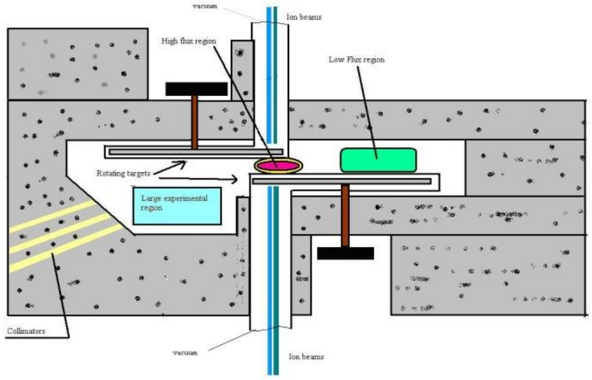

Fig. 1: Schematic of the NSFS' target station.

Figure 2 shows a 3D CAD-based picture of the double rotating target, while in figure 3 is shown the proposed configuration with the primary shielding.

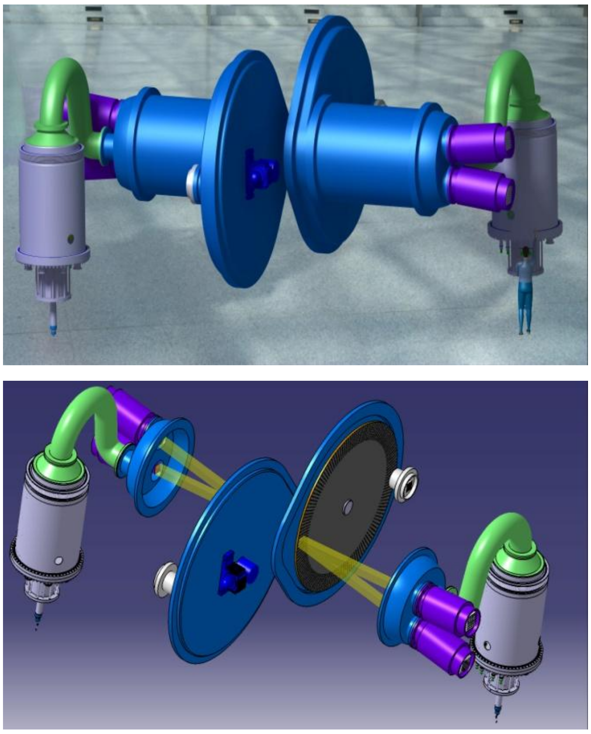

Fig. 2: CAD-based picture of the NSFS' rotating target.

One basic aspect of the proposed neutron source is the use of available and tested technology, e.g. the intense beams are produced by 4x4 MW power Deuterons and Tritons Positive Ion Injectors adapted to produce a rectangular spot of 10x20 cm2 on each rotating target.

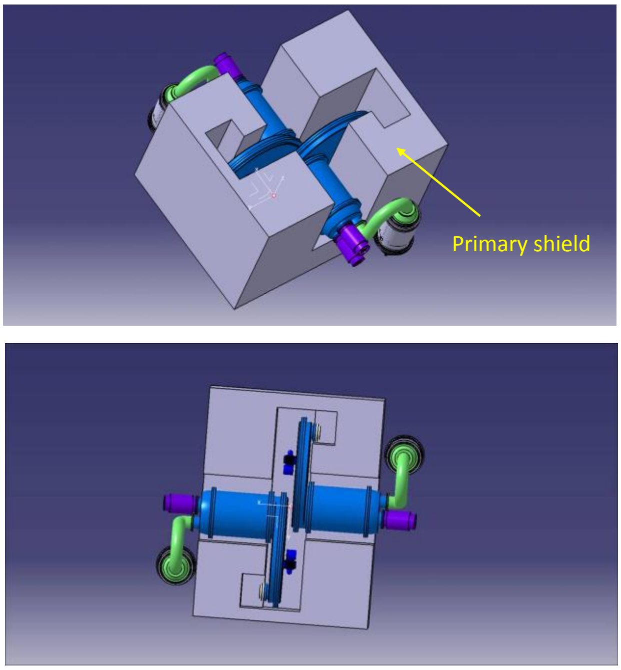

Fig. 3: CAD-based picture of the two rotating target inside the primary shield.

The main design parameters of the rotating targets can be found in Ref. 4. One important issue to be addressed is the thermal analysis on the target that should support an intense power load. Figure 4 shows the target temperature time evolution in one cycle for a beam power of 8 MW.

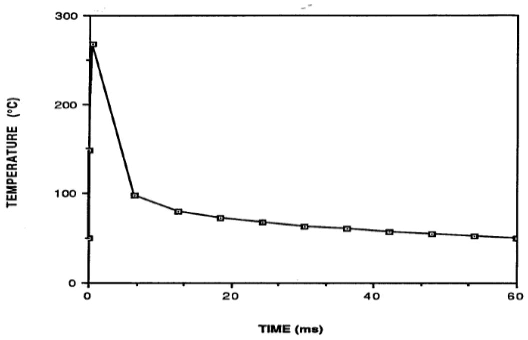

Fig. 4: Temperature of the Titanium surface as a function of time (radius= 2 m, frequency= 1000 rpm, incident beam power density= 40 kW/cm^2 ,one cycle).

The feasibility to load with hydrogen isotopes the titanium surface of the target has been investigated with and “ad hoc” experiment performed using the neutral beam test bed at JET. A deuteron beam has been used to implant, at high fluence rate, deuterium in a mock-up of NSFS target.

The mock-up of the target had a 1.6 ±0.1 µm tick Ti coating whose surface temperature was measured with an infrared thermometer while the bulk target was cooled with pressurized water flowing in apposite channels. A set of calibrated neutron detectors was used to determine the neutron source strength of the D-D reactions which occur during the deuteron bombardment. The measured neutron rate was converted in the amount of deuterium implanted using a neutron yield code developed for the Sorgentina project [4]. The results of these measurements is gathered in figure 5 where the measured deuterium concentration is shown versus the deuteron fluence also at different Titanium surface temperature demonstrating the feasibility of the deuterium implantation also for temperature around 400 °C.

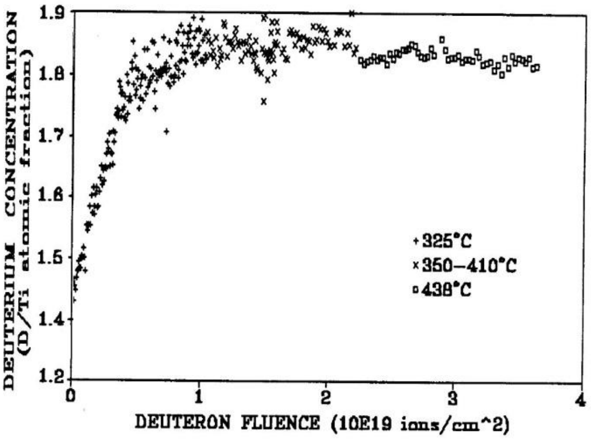

Fig. 5: Measurements of the deuterium implantation during deuteron bombardment in target mock-up.

3 Neutron Yield calculation

As a matter of fact, the neutron production depends on the impinging deuterons energy and the concentration level of D and T into the Ti lattice matrix. This is shown in figure 6, where the number of neutron per deposited power per second is plotted against beam energy. The data in figure 6 were calculated with a dedicated code developed for the Sorgentina project using the procedure suggested by Kim [5], assuming different hydrides content into the Ti matrix.

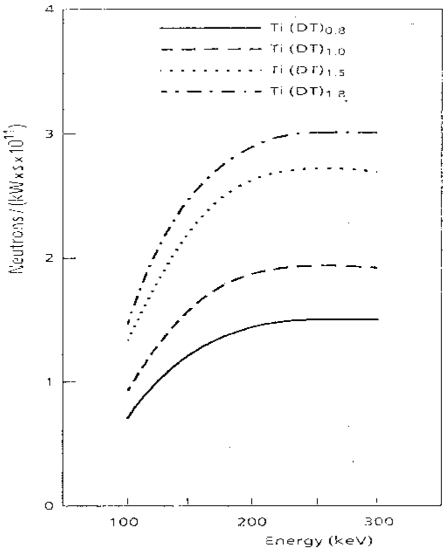

Fig. 6: Neutron yield per kW vs. beam energy from a 50-50% D-T beam striking a Titanium target versus different hydride load calculated with a dedicated code [4].

New Sorgentina Fusion Source is able to produce an high neutron flux region (~ $7x10^{12}$ n/cm^2/s) of about 1200 cm^3. In a restricted volume of 50 cm^3 the neutron flux is ~$1x10^{13}$ n/cm^2/s corresponding to 2 dpa/year in iron. With the target configuration sketched in figures 1,2 and 3, the flux is higher and the iso-flux surfaces, obtained by means of a MCNPX simulation using the modeled configuration in figure 7, are shown in figure 8.

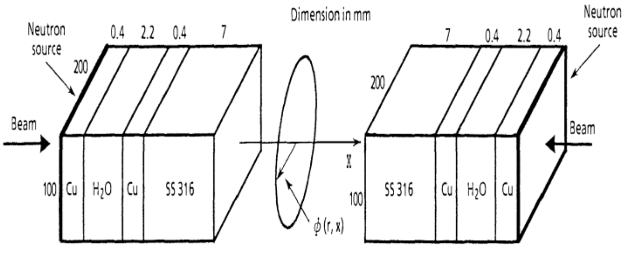

Fig. 7: Simplified MCNPX model used to calculate neutron flux within the region comprised between the two rotating targets.

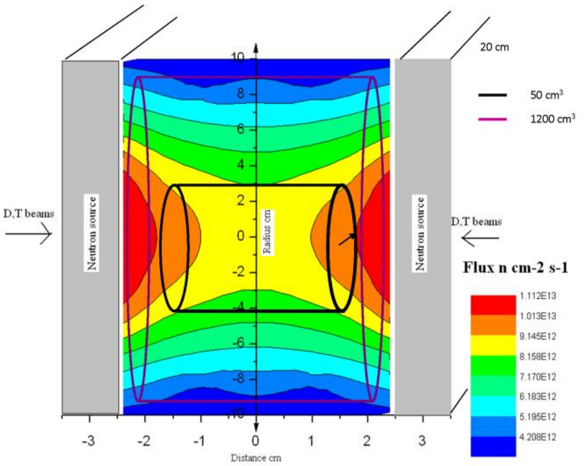

Fig. 8: Iso-flux surfaces in the region between the two rotating target obtained by means of MCNPX simulation.

4. Conclusions

The NSFS facility was described and its main design parameters and expected performances in term of neutron production were discussed. A 14 MeV neutron source like the NSFS may be considered of strategic importance for the fusion community for the experimental activity towards the DEMO machine. Indeed NSFS envisaged activity could be devoted to :
a) carry-out basic studies on 14 MeV neutrons induced damage into irradiated materials in turn validating damage calculation codes (~ 1- 2 dpa/y);
b) verify the influence of nuclear transmutation on the electric characteristics of ceramic insulators, optical fibers and window materials;
c) provide a neutron field were damage cross sections can be tested and/or measured;
d) address basic experimental information for the selection of low activation materials;
e) furnish reliable data about the radiation hardness of materials to be used for diagnostics.

References

[1] EUR FU Brussels / XII - 230/88 Matia 12 lEA Paris.

[2] C.M. Logan and D.W. Heikkinen, Nucl. Instr. Meth. 200 (1982) 105-111.

[3] M. Martone et al. High Flux High Energy Deuterium Ion Implantation, in High Temperature titanium (Preliminary Experimental Tests for sn Intermediate Intensity Neutron Source, Sorgentina) ENEA internal report (June 1992)

[4] M. Martone et al. Feasibility Study of a 14-MeV Neutron Source (Sorgentina) , ENEA internal report (1990)

[5] J. Kim, Neutron Sources Using D-T Mixed Beams Driven into Solid Target, Nucl. Instrum. Methods 145 (1977) 9-17.