Nuclear Instruments and Methods in Physics Research A 684 (2012) 1–6

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

A safety device for the neutron converter of the SPIRAL2 project

G. Acosta [a], M. Avilov [b], J. Bermudez [a,c], M. Blinov [b], P. Logatchev [b], S. Shiyankov [b], L.B. Tecchio [a,*], E. Udup [a,d,e], V. Zaitsev [b]

[a] INFN Laboratori Nazionali di Legnaro, 35020 Legnaro, Italy
[b] Budker Institute of Nuclear Physics, 630090 Novosibirsk, Russia
[c] Universidad Simon Bolivar, Caracas, Venezuela
[d] Horia Hulubei National Institute of Physics and Engineering, Bucharest, Romania
[e] University Polytechnic of Bucharest, Romania

ARTICLE INFO

Article history:
Received 16 December 2011
Received in revised form
11 April 2012
Accepted 16 April 2012
Available online 11 May 2012

Keywords:
Neutron sources
Nuclear reaction
Radioactive ion beams

ABSTRACT

A safety device for the SPIRAL2 neutron converter has been developed to protect the UCx fission target from the possible interaction with the 200 kW primary deuteron beam.

The system consists of a special device called *Delay Window*, (*DW*), which is designed as an integral part of the cooling panels of the neutron converter module. The DW is located between the neutron converter and the fission target. In case of neutron converter failure, this device will absorb the beam and will delay its impact on the UCx target; this delayed time is longer than the interlocks activation time, hence the primary beam operation is safely stopped. The working principle of the DW is based on the well known liquid lead technology. The conceptual design of the Delay Window is presented, as well as the results of the thermo-mechanical simulations and the tests of the prototype. Calculations are done for beam powers of 50 and 200 kW. Simulations are performed with ANSYS code.

1. Introduction

SPIRAL 2 is an European facility aimed to deliver high intensity radioactive ion beams (RIB's) for nuclear physics applications. The RIB's will be produced by the ISOL "Isotope Separation On-Line" method via a converter (i.e., neutron converter) or by direct irradiation. In this facility a deuteron beam impinges on a carbon converter material producing fast neutrons, which will induce fissions on the UCx target. The fission fragments are ionized, accelerated and delivered to the experimental halls. This facility will allow to cover broad areas of the nuclear chart and carry out promptly significant experiments and activities in both fundamental and applied Nuclear Physics (medicine, biology, solid state, etc) [1].

The neutron converter must produce an intense flux of fast neutrons, mainly in the forward direction with respect to the incoming deuteron beam, inducing a fission rate up to 10^{14} fissions/s on the UCx target. The primary beam is characterized by energy of 40 MeV and current of 5 mA (200 kW). A special safety device called Delay Window has been designed in order to protect the UCx fission target from a possible interaction with the primary beam. In case of the neutron converter failure, the 200 kW deuteron beam will impinge on the delay window, the liquid lead alloy flowing inside will absorb the beam and avoid the impact on the fission target.

2. Requirements and performances

The neutron converter has to produce an intense flux of fast neutrons, mainly in the forward direction with respect to the incoming deuteron beam, and enable to induce up to 10^{14} fissions per second in the Uranium Carbide target, located upstream the converter. The primary beam is constituted by deuterons of energy up to 40 MeV and 5 mA current (200 kW).

The neutron converter is conceived as a high speed rotating target, which limits the peak surface temperature of converter materials well below 2000 °C. Nuclear graphite made of natural carbon is a very suitable material for neutron converter construction. In fact, $^{nat}C(d,n)$ reaction is very prolific, especially in the forward direction where the neutron yield is comparable to that generated by other light material converters. The thermal properties of graphite allow a compact geometry (sublimation point of 3632 °C), so the power dissipation from the converter does not demand very sophisticated cooling system, but the heat is simply exchanged by radiation with the water cooled panels. The wheel diameter is 120 cm, and the rotation is carried out by an electrical motor by means of a rotary feedthrough and bearings system.

The thermal power (200 kW) deposited in the converter material is dissipated only by means of thermal radiation. Heat

* Corresponding author. Tel.: +39 049 8068565; fax: +39 049 8068424.
E-mail address: tecchio@lnl.infn.it (L.B. Tecchio).

0168-9002/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.nima.2012.04.070

removal from the production module volume is carried out by water circulating inside cooling panels, connected to the module's walls.

At the beginning of the operation and during a relative long period, necessary to assess the performance of the converter, the facility will be operated at reduced power, up to 50 kW. The suitable neutron converter has been studied for this first period of operations and was designed based on the experience of the 70 kW prototype [2]. The wheel diameter of the 50 kW converter is 52 cm. The remaining components of the neutron converter module remain unchanged.

Two spot sizes have been chosen for the deuteron beam, 20.4 mm (6σ) and 42.6 mm (6σ) for both 50 kW and 200 kW, respectively, with a Gaussian profile on horizontal and vertical direction. In both cases the maximum beam power density is about 70 kW/cm^2.

The neutron converter, the Uranium Carbide target and the ion source are placed inside a module, the "production module", which is surrounded by the biological shielding.

In practice, the "production module" is a shielded box that contains all the sub-systems dedicated to the production of radioactive ions, which becomes highly radioactive and contaminated.

Therefore, removal of the "production module" must be done only by a remote handling device. The disassembling of the "production module", spare parts replacement, or conditioning of elements has to be conducted inside a hot-cell to ensure that the radioactivity is confined.

The current design integrating the neutron converter inside the production module is shown in Fig. 1.1.

In order to be remotely manipulated, the converter design has been conceived as a "sub-module" which can be handled independently from the production module. This "sub-module" (NCM) integrates the converter it-self, the rotation system, the cooling panels, the delay window and all the servitudes required to operate the converter.

The NCM design has been conceived to house both converters, 50 and 200 kW, and to operate under both power conditions. It is requested the replacement only of the graphite wheel according to the required operational power. The cooling panels, the delay window, the driving motor and the servitudes remain the same and may be re-used several times.

The DW is an integral part of the full system for the production of radioactive beams and is located inside the production module, integrated to the rear cooling panel of the neutron converter; it is equipped with its own control system which has been developed to be compatible with the general control system of the facility.

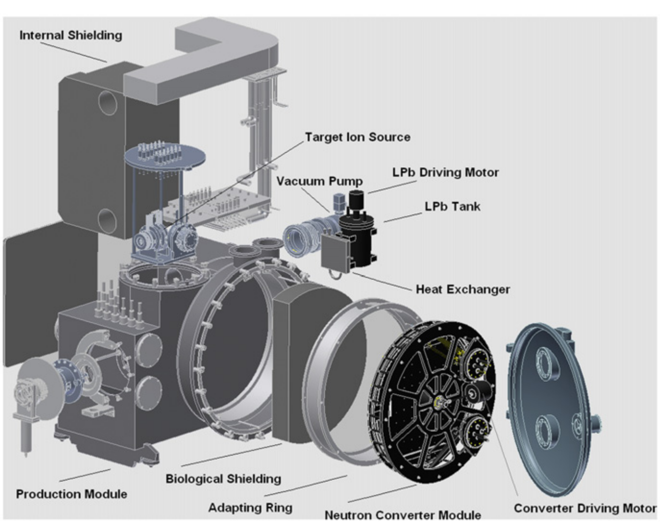

Fig. 1.1. View of the neutron converter integrated inside the production module.

The "removable shielding" allows the use of the NCM for different UCx target configurations, by modifying the "mechanical adaptation" ring.

3. The delay window

To protect the UCx target from the interaction with the deuteron beam, a "Delay Window" (DW) is located in between the neutron converter and the UCx target and is integrated on the rear cooling panel of the converter assembly.

A continuous flow of liquid lead-tin alloy (LPb, 90% Pb and 10% Sn), at high temperature ($>320\,^{\circ}$C) is circulating through the DW with velocity bigger of 1.5 m/s. In case of failure of the neutron converter, the deuteron beam impinges directly on the wall of the DW which will be melted in a very short time (<5 ms), then the deuteron beam is dumped in the LPb jet. The thickness of the LPb inside the DW is 5 mm (stopping length = 1.8 mm) and it is sufficient to absorb completely the deuteron beam during 60 s, time enough to stop the beam operation.

The LPb is also acting as coolant, so the DW surfaces (made of AISI 316LN stainless steel) are blackened ($\varepsilon=0.95$) to enhance their heat absorption efficiency. The main parameters characterizing the DW are listed in Table 2.1.

The LPb tank, the LPb pump and its electrical motor driver and the DW heat exchanger are located externally to the production module.

The DW set-up has been conceived to be the same for both operating conditions (50 and 200 kW). The whole LPb system is standing at high voltage potential (60 kV), the same of the UCx target and ion source.

The DW shows an L's shape with an active length about 200 mm (see Fig. 2.1). A lead thickness of 1.8 mm is enough to absorb the 40 MeV deuteron beam; for safety reasons the active part of the DW is 5 mm thick and 60 mm wide. The front wall of the DW is 2 mm thick and is melted in less than 5 ms by the deuteron beam. The rear wall is 7 mm thick, including the lead heating system. The main parameters characterizing the DW are listed in Table 2.2.

The DW is clamped on its central part to the rear cooling panel and is free to expand by heat along the longitudinal direction. The LPb is flowing inside two AISI 316L stainless steel flexible tubes and the heat expansion (about 6 mm) is compensated by their flexibility.

A stainless steel tank contains 30 L of LPb (340 kg) and the pump for its circulation. The pump is driven by an electrical asynchronous motor, analogous to that one used to drive the converter wheel. The LPb tank is mechanically coupled to the production module, together with the heat exchanger.

The heat exchanger consists of a box made of stainless steel AISI 316 L ($350\times500\times150$ mm^3); the LPb flows through the

Table 2.1
Main parameters of the delay window.

Parameter	Value	Measure unit
Thickness of LPb alloy jet (70 MeV deuteron)	5	mm
Width of the delay window	60	mm
Thickness of the wall (stainless steel)	2	mm
Velocity of the LPb alloy	>1.5	m/s
Temperature of LPb alloy	<350	°C
Time of melting first wall	<5	ms
Evacuation rate of LPb in case of failure (200 kW)	~0.5	l/s
Active protection time in case of failure (200 kW)	~60	s