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FUSION-8356; No. of Pages 5
ARTICLE IN PRESS
Fusion Engineering and Design xxx (2015) xxx–xxx
Contents lists available at ScienceDirect
Fusion Engineering and Design
journal homepage: www.elsevier.com/locate/fusengdes

Feasibility study of a neutron activation system for EU test blanket systems

Kuo Tian [a,*], Pattrick Calderoni [b], Bradut-Eugen Ghidersa [a], Axel Klix [a]

[a] Institute for Neutron Physics and Reactor Technology, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
[b] Fusion for Energy(F4E), Barcelona, Spain

HIGHLIGHTS

- This paper summarizes the technical baseline and preliminary design of EU TBM Neutron Activation System, briefly describes the key components, and outlines the major integration challenges.

ARTICLE INFO

Article history:
Received 24 August 2015
Received in revised form 28 October 2015
Accepted 24 November 2015
Available online xxx

Keywords:
Neutron activation system
ITER
Irradiation
Neutron flux
TBM

ABSTRACT

The Neutron Activation System (NAS) for the EU Helium Cooled Lithium Lead (HCLL) and Helium Cooled Pebble Bed (HCPB) Test Blanket Systems (TBSs) is an instrument that is proposed to determine the absolute neutron fluence and absolute neutron flux with information on the neutron spectrum in selected positions of the corresponding Test Blanket Modules (TBMs). In the NAS activation probes are exposed to the ITER neutron flux for periods ranging from several tens of seconds up to a full plasma pulse length, and the induced gamma activities are subsequently measured. The NAS is composed of a pneumatic transfer system and a counting station. The pneumatic transfer system includes irradiation ends in TBMs, transfer pipes, return gas pipes, a transfer station with a distributor (carousel), and a pressurized gas driving system, while the counting station consists of gamma ray detectors, signal processing electronic devices, and data analyzing software for neutron source strength evaluation. In this paper, a brief description on the proposed TBM NAS as well as the key components is presented, and the integration challenges of TBM NAS are outlined.

1. Introduction

The objective of the ITER facility is to demonstrate the technological and scientific feasibility of fusion energy. The testing of tritium breeder blanket concepts in the ITER facility is considered as an essential milestone in the development of future D-T fusion power reactors ensuring tritium self-sufficiency. Six Test Blanket Modules (TBMs) [1,2], as part of six respective Test Blanket Systems (TBSs), are planned to be installed in three equatorial ports of ITER to investigate the performance of different tritium breeding blanket concepts. The EU is responsible for the delivery of a Helium Cooled Lithium-Lead (HCLL) TBS and a Helium Cooled Pebble Bed (HCPB) TBS, which are collocated in one of the three dedicated port cells [3].

In the TBMs, the neutron flux is an essential parameter for many of the prospected TBM experiments from the first D-D phase to the later D-T phase of ITER operation and for validation of capabilities of neutronic codes and data libraries. Neutron activation techniques have been used in several tokamaks to determine local neutron fluence or energy spectrums [4–6]. ITER Neutron Activation System (NAS) has been designed to evaluate the total neutron production from D-D and D-T plasmas [7–10]. For EU HCLL and HCPB TBMs, NAS is also proposed to characterize neutron flux and tritium production rates at several locations inside the TBMs by means of placing activation probes inside TBMs for a certain time period and measuring the induced activity after extraction.

This paper summarizes the functional description and process flow of the EU TBM NAS, including a brief description of the NAS system and its key components. The major integration challenges of the TBM NAS to the TBSs are also discussed.

* Corresponding author. Tel.: +49 721 608 24026; fax: +49 721 608 22996.
E-mail address: kuo.tian@kit.edu (K. Tian).

http://dx.doi.org/10.1016/j.fusengdes.2015.11.039

Please cite this article in press as: K. Tian, et al., Feasibility study of a neutron activation system for EU test blanket systems, Fusion Eng. Des. (2015), http://dx.doi.org/10.1016/j.fusengdes.2015.11.039

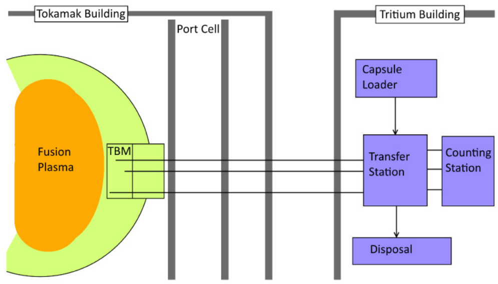

Fig. 1. Schematic of the layout of TBM NAS (only one TBM is shown).

2. Technical baseline and system description

The TBM NAS is expected to measure the absolute neutron fluence and the absolute neutron flux with information on the neutron spectrum in selected positions in the TBM. The requirements of the TBM NAS include:

(a) During the plasma operation phase, activation material probes are sent to Irradiation Ends (IEs) in dedicated positions inside the TBMs;
(b) The probes stay in the IEs and are irradiated for a certain time period (several tens of seconds up to a full plasma pulse length);
(c) After irradiation, the probes must be extracted from the IEs to a counting station away from the irradiation source for gamma analysis.

The design of TBM NAS presented in this paper aims at fulfilling the above mentioned requirements. To some extent the TBM NAS will be similar to the ITER NAS [7]; however, the TBM NAS faces more challenging environmental conditions and its design will reflect this. The critical conditions include: the IEs of the TBM NAS will be placed inside the Breeding Units (BUs) of TBM at temperatures up to 550 °C (in HCLL TBM), 650 °C (in HCPB TBM), or even higher; the pipes will have to penetrate all of the interface plates of the TBMs; the routing of capsule transfer pipes and return gas pipes are more challenging due to the limited space available in the instrumentation pipes as well as inside the TBMs, etc. In the current TBM NAS design, helium, instead of air, is selected as the driving gas because the IEs are located inside of the TBMs which are cooled by helium. Argon or nitrogen is not selected as driving gas due to activation properties under neutron irradiation.

A general layout of the proposed TBM NAS is presented in Fig. 1 (only one TBM is shown). The TBM NAS consists of a pneumatic transfer system and a counting station. The pneumatic transfer system includes a set of helium tanks, a transfer station, transfer pipes/return gas pipes, and the IEs. The counting station includes gamma ray detectors (one for each IE for optimum performance) and pulse processing electronics. As an example, Fig. 2 shows the preliminary process flow diagram of the HCLL TBM NAS with only one IE and one pair of transfer pipe/return gas pipes illustrated in detail. In total six individual NAS IEs are expected to be installed to the two EU TBMs: three are installed in the HCLL TBM and another three in the HCPB TBM.

The left part of Fig. 2 shows an example IE, a transfer pipe with a capsule inside, and a return gas pipe. Each TBM NAS IE is connected with the transfer station, which is located in a glove box in the tritium building, through one transfer pipe and one corresponding return gas pipe. Between the BU and the transfer station, all of these pipes must penetrate the wall of tritium building, the wall of Tokamak building, the port cell, pipe forest, and the corresponding port plug. This arrangement concept for pipes is replicated for each NAS IEs for the HCLL and HCPB TBM.

On the right side of Fig. 2, in the tritium building, a transfer station is represented with its connections to the following equipment: a capsule loader, a counting station, a Helium Driving Gas Tank (HDGT), a Helium Suction Tank (HST), and a disposal bin.

One High Pressure Buffer Tank (HPBT) and one Low Pressure Buffer Tank (LPBT) are also arranged in the glove box to provide helium supplement to the HDGT or store the surplus helium from the HST, respectively, so that the pressures in the HDGT and HST can be finely controlled. A compressor connects the two buffer tanks and delivers helium from the LPBT to the HPBT to keep the desired pressures in the tanks. From the helium tanks, a connection from ITER general helium supply and the connections to a detritiation system to remove the tritium that might permeate inside the pneumatic transfer system are also indicated.

In the current design of EU TBM NAS, two transfer stations, two sets of helium tanks, two compressors, and two capsule loaders are considered for the HCLL NAS and HCPB NAS respectively. However, only one common counting station and one common disposal bin are expected to be installed in the glove box (in the tritium building) for the two pneumatic transfer systems.

For a neutron flux measurement inside the TBM, a capsule with sample materials is loaded from the capsule loader to the transfer station, distributed to selected transfer lines, and then sent to the corresponding IE. During this procedure, the transfer pipe is connected to the HGDT and simultaneously the return gas pipe to the HST. The pressure difference between the two tanks is applied to the NAS capsule to push the capsule moving towards the corresponding IE. The positions of the capsules are monitored with photo sensors coupled to the transfer pipes with optical fibers. After reaching the IE, the capsule is exposed to the neutron irradiation for a certain time period. Thereafter the capsule is sent back to the transfer station. In this capsule retrieving procedure, the return gas pipe is connected to the HGDT, while the transfer pipe to the HST. Subsequently, the irradiated capsule will be transferred to the counting station for off-line analysis. The functioning of the TBM NAS is expected to be controlled by a programmable logic controller.

3. Key components description

3.1. Capsule

An irradiation capsule is the carrier that encapsulates sample materials and brings them from the capsule loader to an IE by pneumatic driving system. After being irradiated in the IE, the capsule brings the sample materials back to the transfer station and then to the gamma counting station.

The size of the capsule is determined by the space restrictions of maximum tubing diameter and minimum activation material weight to perform meaningful measurements. In the current TBM NAS design, a suitable capsule size has been preliminarily selected as 8 mm in outer diameter and 15 mm in length. This selection is based on Monte Carlo neutron spectra calculations on induced activity for representative positions in the HCPB TBM and inventory calculations. These estimations are also supported by experimental results of preliminary activation tests [11–13].

During the operation of the TBM NAS, the capsules are transferred between the places which have dramatic temperature differences from room temperature to up to several hundred degrees Celsius. In addition, the capsules may be exposed to considerable mechanical stress from impacts in the transfer station, IEs, and the gamma counting station. Hence, the material of the capsule is selected taking into account mechanical, thermomechanical, and activation properties. CFC (carbon fiber-reinforced carbon) was suggested for the ITER NAS capsule [9], and is also considered for

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