STUMM — TEST MODULE FOR A HIGH INTENSITY NEUTRON STRIPPING SOURCE*

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An intense neutron source based on the stripping reaction between deuterium and lithium will produce the neutron spectrum similar to that induced by the deuterium–tritium reaction in fusion plasma reactors. This accelerator source will be built for tests prior to the operation of the future tokamaks, *e.g.* DEMO. As till now, no experimental results exist for such a kind of source. All parameters of the neutron and photon fields, and working conditions are foreseen based on theoretical and numerical calculations for the radiation transport. For verifying these predictions, it is necessary to build a special test module, called STUMM, that means the Start-Up Monitoring Module. This paper presents a concept of STUMM including a description of the main objective of the module, proposition of its shape and description of the foreseen experimental instrumentation.

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1. Introduction

In order to build the future tokamaks like DEMO (Demonstration Fusion Power Reactor), the suitable materials for construction must be ensured. Such materials must be able to withstand for long time extremely hard conditions like high radiation and high temperature. IFMIF-DONES (International Fusion Materials Irradiation Facility — DEMO-Oriented Neutron Source) will be a neutron source based on the stripping reaction between deuterium and lithium which will produce the neutron spectrum similar to that induced by the deuterium–tritium reaction in fusion plasma reactors [1]. The following reactions will be typical for IFMIF-DONES: $^7\mathrm{Li}(d,2n)^7\mathrm{Be}$,

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^{6}Li$(d,n)^7$Be, ^{6}Li$(n,T)^4$He. In this source, an intense D^+ beam of a 40 MeV energy and intensity of 125 mA will strike a liquid lithium target, flowing at a speed of 15 m/s, providing an intense neutron flux density, about 10^{15} $n/\text{cm}^2/\text{s}$, with a broad energy peak near 14 MeV. For verifying all predictions, a special test module, called STUMM (Start-Up Monitoring Module) is under development by a group from the Institute of Nuclear Physics Polish Academy of Sciences (IFJ PAN) and the National Centre for Nuclear Research (NCBJ) [2, 3]. The expected neutron energy spectrum in position of the STUMM will be in a wide energy range from thermal to fast.

2. Short description of the system

The STUMM will be positioned inside a so-called Test Cell (TC), as close as possible just behind the IFMIF-DONES neutron source, *i.e.* the lithium target backplate (BP), during the commissioning phase of IFMIF-DONES. Amid such position, this module will be working in extremely conditions foreseen as: the temperature up to 600°C, neutron radiation field up to 10^{15} $n/\text{cm}^2/\text{s}$ and a dose from photons with the order of GGy per year. The TC will be filled out of helium gas under pressure up to 200 hPa. The STUMM must be designed to accept a dose of at least 5 dpa. The STUMM, like other objects inside the TC, will experience significant nuclear heating, peaking at about 3 W/g (for steel) in the beam center. The geometrical parameters of the STUMM such as: size, geometry, weight, positioning system, gas connections, electrical connections must be compatible with the design of the TC and all the Remote Handling systems involved in the handling of STUMM. In order to minimize the impact of this module in the design of the TC, the STUMM must be designed to use the gas, power supply and instrumentation connections already available in the TC for the rest of the modules. Three main tasks for a STUMM are foreseen: to characterize the neutron source, verifying the neutronic calculations and to characterize the radiation field inside the High Flux Test Module (HFTM — module dedicated for irradiations). Dedicated instrumentation aimed to provide the desired information such as: neutron and photon flux density, gamma ray dose and temperature will be installed inside the STUMM in the part called container (Fig. 1). The container will be divided by stiffening plates into eight compartments where instrumented rigs will take place. Each rig inside will be divided into 5 levels. The whole active area will be divided into 40 rectangular segments with loaded no more than 240 active sensors. Apart from active sensors in these segment, there will be installed the other sensors, wires, gamma thermometers, temperature sensors, cables and connectors. The middle part of the active area will be situated exactly opposite to the beam footprint to characterize the neutron source.

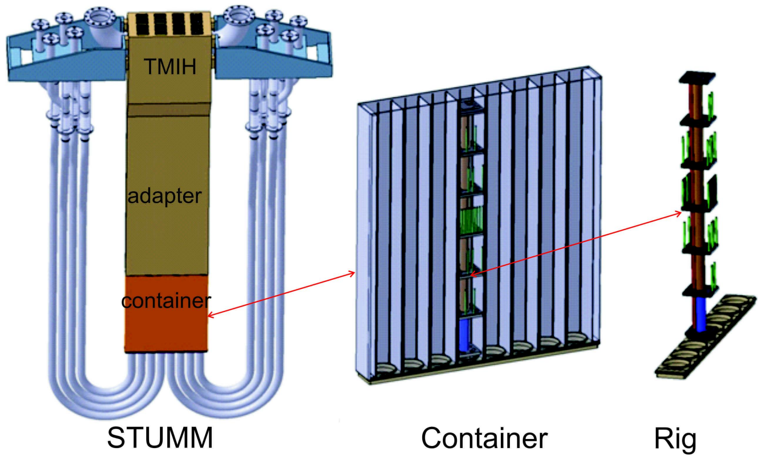

Fig. 1. STUMM — general view of STUMM and its main components.

Construction of the rigs will allow to distribute and to fasten a number of sensors and adequate cables without essential impact on cooling gas flow. To bring the work of sensors suitable conditions must be ensured. The appropriate cooling system must be able to reduce temperature inside the STUMM to 200°C–250°C what is related with the cooling gas pressure of 300 kPa. This assumed temperature is related with its maximum permission value necessary for correct operation of dedicated sensors. The helium gas will circulate in eight feed pipes up to the container module inlets at the bottom of the STUMM and will be transported through the rigs, attachment adapter and will be reunited in the Test Module Interface Head (TMIH) into the two lateral exit pipes.

3. Sensors dedicated for STUMM

Needs of sensors dedicated for STUMM are strongly related with conditions inside this module and have to be characterized by a long radiation resistance and relatively small radiation sensitivity.

The STUMM instrumentation can be divided into two categories:

— Passive detectors — that can be only evaluated after unloading from the TC. Passive sensors, *i.e.* the neutron activation detectors are the most convenient to be used for characterization of the facility in the start-up phase. The neutron activation detectors are the only ones which allow obtaining the absolute value of neutron flux density. Therefore, they play a crucial role in the calibration of other neutron diagnostics. The neutron activation detectors can be also used to determine the neutron energy spectrum. A set of activation foils and wires or balls allows determining in TC the spatial distribution of both the neutron flux density and the neutron energy spectrum. The amount of atoms to be activated should be estimated beforehand, depending on the expected flux, the sensitivity of the mother isotopes, the period of the daughter isotopes, the irradiation time and the delay before measurement, in order to have a residual activity between 10^2–10^5 Bq in front of the detectors. The highest accuracy is achieved without attaining the saturation phenomenon but makes the irradiation time shorter.

— Active sensors — could be used as on-line monitors to determine radiation conditions inside STUMM. The on-line sensors will not need to be changed during commissioning phase of IFMIF-DONES if they are reliable enough.

— Rabbit system — could be used in the case of activation of short-lived isotopes. It allows using a wider range of the activation reactions, what significantly improves determination of neutron energy spectrum (increases its resolution). However, the counting station need to be equipped with a set of gamma spectrometers: scintillation spectrometers for regular gamma acquisition and High-Purity Germanium (HPGe) spectrometers for accurate activity determination. Installing a pneumatic rabbit system would be extremely valuable. Such a system simplifies delivering the irradiated samples to the counting station.

3.1. Passive sensors

A set of purpose chosen foils, wires and balls is needed both to accurately determine neutron flux/fluence spatial distribution and neutron energy spectrum. They should be also used to calibrate other neutron diagnostics. Due to requirements of material investigation, special attention should be paid to fast neutron spectra — threshold nuclear reactions should be used. Thermal and epithermal neutrons should be recorded as well. The half-life of considered reaction products should be adjusted to minimal available time of removing the samples from the TC. One should note that some of activation reactions recommended for IFMIF-DONES applications have only been tested with fast neutrons, *e.g.* [4]. In the case of real DONES TC conditions, the thermal neutron component shall be significant. Therefore, selection of activation reactions should be performed very carefully and based on more accurate neutron spectrum estimation. One should note that activation wires shall be cut after withdrawal from the TC. Mass of foreseen foils and pieces of cut wires should allow obtaining suitable activity of the reaction products. Activity of the samples should be in the range of 10^2–10^5 Bq. A set of gamma spectrometers is a part of the activation monitor measurement system. In particular, the HPGe detectors allow for an accurate determination of a sample activity. The activation samples have to be made of very pure materials in order to avoid undesirable induced activities from minor additives. Thermal neutron activation detectors shall be diluted, *i.e.* to be an aluminum alloys.

3.2. Active sensors

The fast neutrons are the prime objects to be investigated with the STUMM device. They should be measured by means of a number of methods to assure result credibility. The fission chamber could be used as an on-line monitor to determine a density of fast neutron flux. They are characterized by relatively low gamma-ray sensitivity. The ^{238}U coating of a chamber is a preferred solution due to relatively high sensitivity for fast neutrons. The fission chamber with ^{238}U coating is suitable for both low-power and high-power ranges of IFMIF-DONES operation. In the low-power range, it is used in pulse counting mode. In the high-power range, it is typically used in a current mode. However, even very small content of ^{235}U in uranium coating causes problems in a signal analysis. A necessary precise determination of a small ^{235}U impurity could be difficult as well. The fission chamber with ^{235}U is not recommended due to a high burn-up effect. To ensure a proper interpretation of fission chamber recordings, the ionization chamber is required. It allows not only discriminating the neutron signal but also determining the gamma-ray dose rate. Self-Powered Neutron Detectors (SPND) are widely used in nuclear reactors and can be applied as neutron flux monitors. A small and easy to use the SPNDs detectors do not need to be powered, and their signal is easy to read and interpret. Beside of thermal neutron SPNDs, it is strongly recommended to install fast-neutron-sensitive-only SPNDs. Such detectors are currently under investigation, *e.g.* at the NCBJ MARIA reactor. Particular SPND emitters, both for thermal and for fast neutrons, should be selected based on foreseen neutron energy spectrum and should be an issue of further careful investigation. The output signal of SPND has a very low current: 10^{-14}–10^{-7} A. The professional pico-ammeter is therefore needed.

Nuclear heating calorimeter allows for quantification heat deposition in the material sample used as the calorimeter core. This may be graphite, aluminum, stainless steel or other material. It consists of a sample rod enclosed inside housing. The temperature profile within the calorimeter provides information on the heat generation rate directly in the sample of the material applied and allows to determine nuclear heating characteristics. By using several calorimeters with different materials, it is possible to verify heat generation at each of the material. The KAROLINA calorimeter developed in NCBJ, MARIA reactor, deserves a special attention [5]. The out-of-pile calibration methodology allows to save time and space during measurement [6]. Time response of this sensor is just around a few minutes (for around 5 W/g) and it does not need any electrical heating elements or movements of the sensor during measurements. There is a need to transform this sensor from water cooling into the gas cooling according to the characteristic of the STUMM cooling system. All the research on this development like manufacturing of this sensor is in the frame of NCBJ activities. The KAROLINA calorimeter for gas cooling environment could be tested with other instrumentation using specially designed fast neutron irradiation channel in the MARIA reactor. Gamma-thermometer measurements are devoted to the nuclear heating determination in stainless steel material [7]. The measurement is based on a temperature difference between a core of the sensor and a cooling environment — without an absolute temperature measurement. This is performed by using of the K-type differential thermocouple. Among variety types of gamma thermometers, one should pay attention to designed and manufactured by the Belgian Nuclear Research Centre SCK-CEN [8]. New gamma thermometer, adapted for gas-only working environment needs to be developed. Fast neutrons could be also detected via the Cherenkov radiation [9–11]. The materials which could be used to detect neutrons by means of the Cherenkov radiation are, among others: quartz ($SiO_2$2), sapphire (Al_2O_3), spinel ($MgAl_2O_4$) and PMMA. Other glasses with neutron-sensitive dopants, not commercially available, should be manufactured [10, 11]. The K-type thermocouples with (Al_2O_3) insulation has a linear response between 0°C and 450°C and can be suitably reproduced by polynomial fit up to 1400°C. Furthermore, this type of thermocouple has a good resistance under irradiation, so they are recommended to use in STUMM. Most of the sensors dedicated for STUMM, except gamma-thermometer detectors, are commercially available, but manufactured only on demand.

3.3. Rabbit system

The rabbit system is foreseen to be located at the back of the STUMM as independent system. At least four pneumatic, simple U-shaped tubes under pressure should be considered. The activation balls can be blown in the activation channels. At the bottom of the tube, a restriction must be foreseen to prevent the ball flying in the exhaust tube. In each channels multiple activation balls can be inserted. The restrictions are placed in such a way that the one or many balls must be kept immobile at the level of the footprint and at the same time must be lift out. The position of the restriction must be chosen beforehand in a function of the amount of balls used or additional balls has to be inserted. The pneumatic systems for each rabbit should be independent.

3.4. Cables and connectors

The manufacturer shall provide detectors equipped with the dedicated data transmission cables, adequate for the given environmental conditions. The existing technologies allow for data transmission cables to be capable of withstanding temperatures from liquid nitrogen up to 1500°C. The latter extremes, however, are typical for emergency situation where the cables are supposed to survive just long enough to send distress or shut down signal. For regular use, temperatures are not expected to exceed 200°C–250°C for the vast majority of the offered products. The higher temperatures, up to 400°C, require glass fibre cables braiding and mica insulators, and the cabling is not expected to be rearranged after installation.

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