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Development of a new fusion power monitor based on activation of flowing water

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Abstract

A new approach has been proposed for monitoring D–T neutrons in the system using neutron activation of flowing water via the $^{16}O(n,p)^{16}N$ reaction. The basic idea of the approach is to utilize the Cherenkov light, which is produced by energetic β-particles from ^{16}N in water, in the vicinity of a neutron source and then transmit the light by an optical fiber to the remote light sensor. Further feasibility studies require development of a water Cherenkov detector with an efficient light collection system that satisfies neutron monitoring requirements. Two different designs of the water Cherenkov detector with a fiber readout, as well as results of their irradiation tests are presented in the paper. Designs and the experimental setup are not yet optimized for best performance; obtained detector parameters demonstrate potential capabilities of the proposed approach.

Keywords: D–T neutrons; ITER; Neutron monitor; Water activation; Cherenkov light; Fiber readout

1. Introduction

Water flowing in the vicinity of the D–T neutron source becomes radioactive. It is proposed to utilize this phenomenon for fusion power monitoring in ITER [1], since the dominant activation product, ^{16}N, is produced exclusively by 14 MeV neutrons via the $^{16}O(n,p)^{16}N$ reaction [2]. The ^{16}N decays by beta emission (100%) with a half-life of 7.13 s and produces several groups of high-energy β-particles (maximum endpoint energy 10.42 MeV) and γ-rays (6.128 MeV and 7.115 MeV) [3]. Considering the ^{16}N decay scheme, several options exist for nuclide activity measurement. Presently, ^{16}N activity is measured using a γ-ray scintillation detector [1,2]. However, this technique leads to an insufficient time resolution and the delay of the neutron monitor response, since water has to transfer the ^{16}N from the production point to the position of a remote γ-detector

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located at a distance of several dozen meters according to the ITER design.

In order to overcome these disadvantages a new approach has been proposed [4]. The presented approach solves problems associated with the response delay and temporal resolution, which are the most important drawbacks of the technique based on γ-ray detection. The basic idea of the new approach is to utilize the Cherenkov light, which is produced by energetic β-particles from ^{16}N in water in the vicinity of a neutron source, and then transmit the light by an optical fiber to the remote light sensor located in any selected place.

The first experimental phase was completed [5] in support of this idea. Its objective was to examine the ^{16}N activity measurement using a remotely located Cherenkov radiator optically coupled with a light sensor, without transmitting light by an optical fiber. Further research requires development of a detector with a fiber readout in order to place the Cherenkov radiator next to the neutron source and transmit the generated light by an optical fiber to the remotely located light sensor. The most critical concern in this topic is the efficiency of the light collection system that has to function in a radiation environment. From the presented point of view, the key objectives are:

- designing a water Cherenkov radiator with a light collection system based on different principles;
- testing detectors inside and outside the D–T neutron source limits;
- evaluating temporal detector parameters.

Two different designs for the Cherenkov detector, as well as results of their irradiation test, are presented in the paper. Designs are not yet optimized for best performance, they serve as basic guidelines for further elaboration upon this topic.

2. Design of the light collection system of the water Cherenkov detector

Basically, the number of Cherenkov photons emitted per electron is only several hundred per MeV (much smaller compared to scintillation photons), therefore for effective detection of the ^{16}N nuclide, it is very important to collect a maximum amount of light [5]. The detector consists of a water Cherenkov radiator, a light collection system, an optical fiber bundle for transmission of the collected light and a remotely located light sensor. Two different principles have been used to design the light collection system.

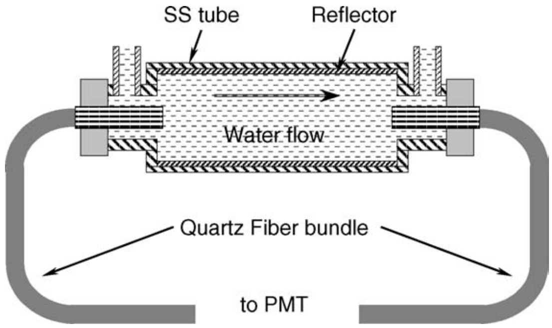

Fig. 1. Schematic illustration of the Cherenkov detector with a quartz fiber readout.

The first principle is based on collection of the direct and diffusive Cherenkov light by quartz fibers. The radiator is viewed by quartz fibers that trap the light within the fiber acceptance cone. A schematic detector design is shown in Fig. 1 and is elaborately described in the reference [6]. The radiator is a stainless steel tube with dimensions of 10 cm in length and a 2.6 cm inner diameter, which is filled with water flowing from the vicinity of a D–T neutron source. The inside walls are covered with a 0.3 cm thick Teflon layer. The radiator is viewed by two quartz fiber bundles inserted inside the water at the opposite side of the radiator. Each fiber bundle contains 20 quartz fibers with a fiber diameter of 0.1 cm. The other side of the bundle was optically connected to the photomultiplier tube (multialkali photomultiplier tube with a quartz window, Hamamatsu, R1463P). The light collection in this system was far from optimum, since a small fiber sensitive area results in a relatively poor coverage of the radiator surface. Two fiber bundles allow the use of a counting technique with a coincidence signal from two PMTs for registration of ^{16}N activity.

The second principle is based on absorption of Cherenkov light produced in the water radiator by wavelength-shifting (WLS) fiber and re-emitting at a longer wavelength inside the fiber. This principle was selected because a relatively high fraction of re-emitted light can be trapped in the fiber by a total internal reflection and guided to the remote light sensor. Due