Study of a lost alpha-induced gamma-ray detection system for ITER

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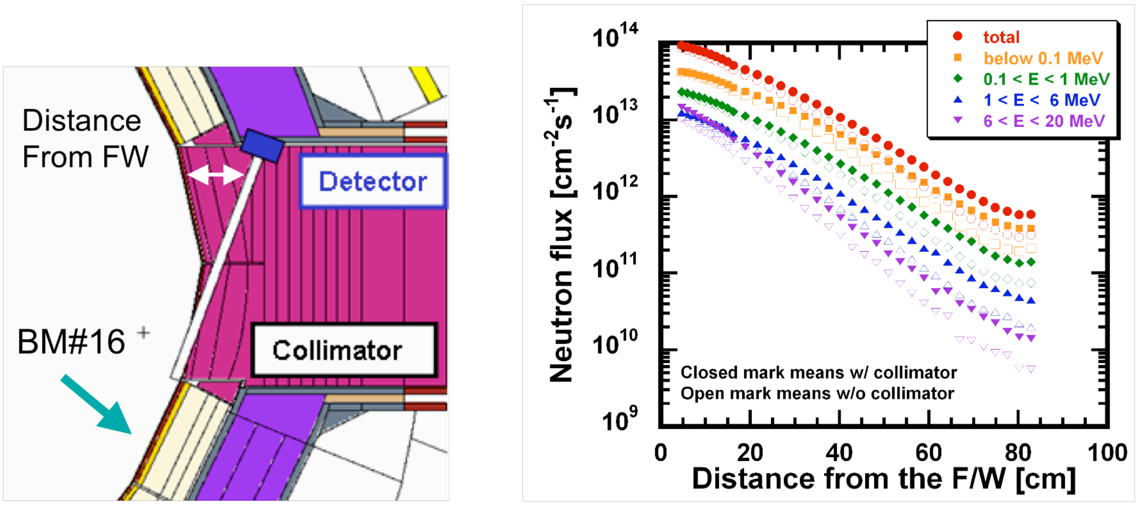
Abstract

The concept of lost alpha measurement by 4.44 MeV gamma ray detection produced by the nuclear reaction $^{9}\mathrm{Be}(\alpha,\mathrm{n}\gamma)^{12}\mathrm{C}$ was examined for ITER. A MCNP calculation was carried out to evaluate the neutron flux in the port plug, where a gamma-ray detector is supposed to be located. The results showed the total neutron flux was at least $10^{11} \sim 10^{12}$ $\mathrm{cm^{-2}s^{-1}}$ at the detector location. One of the candidate detectors for the 4.44 MeV gamma-ray measurement is a Ce:LSO scintillator. The response of Ce:LSO to neutrons was estimated for each neutron energy region, and then they are convoluted with the neutron flux at the detector location. It was found that an additional neutron shield layer is needed to reduce neutron fluxes by a factor of 10^3 at least.

1. Introduction

In burning plasma experiments on the International Thermonuclear Experimental Reactor (ITER), escaping alpha particle diagnostics is important for the first wall (F/W) protection, the burning control, and for the study of the fundamental alpha particle confinement property and various types of collective phenomenon driven by super-Alfvénic alpha particles [1]. Among various methods proposed for escaping alpha particle measurement, the concept of 4.44 MeV gamma ray detection produced by the nuclear reaction $^{9}\mathrm{Be}(\alpha,\mathrm{n}\gamma)^{12}\mathrm{C}$ [2] is attractive because of potential capability of wide coverage of the wall[3] .

However, it is anticipated that the neutron-induced noise is so high that the gamma detector might be saturated. In the present work, the neutron flux at the possible location for the gamma detector was calculated by using a neutron transport code, and the induced noise level was estimated. Possible provision for improvement of signal to noise ratio was proposed.



(a) (b)

Fig. 1 Schematic view of possible arrangement of the lost alpha-induced gamma-ray detection system on ITER (a). The calculated neutron flux at the detector in the port plug is plotted against the distance from the first wall (b). Open marks indicate the results with a collimator

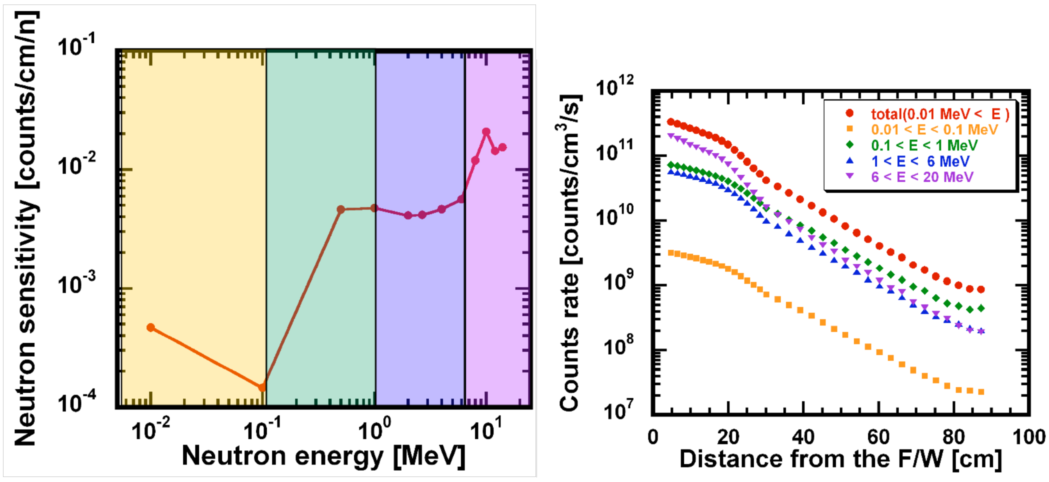
2. MCNP calculation for neutron flux estimtion at the detector location

It is predicted that alpha particles are escaping toward downward and bombarding the first wall on the outer blancket modules in ITER[3-5]. Then the possible location for gamma-ray detectors is in one of the equatorial port plugs, as shown in Fig. 1(a). A collimator viewing the alpha loss region will be equipped for each detector.

A neutron transport calculation was carried out by using the MCNP code [6] to evaluate the neutron flux in the port plug. Here, A-lite model [7], a 40° sector ITER geometrical model with the 500 MW fusion plasma neutron source (scenario 2) was used to calculate neutron fluxes and neutron energy spectra. The results for a detector viewing the blanket module # 16 are shown in Fig. 1(a), as a function of a distance from the first wall (FW) surface, for each neutron energy region. The total neutron flux was at least 10^{11} ~ 10^{12} cm^{-2} s^{-1} at the location of detector (~80 cm from the FW). The collimator increases the neutron flux by a factor of 2.

3. Neutron response of a LSO scintilator and esitmation of neutron-induced background

One of the candidate detectors for the 4.44 MeV gamma-ray measurement is a Ce:LSO scintillator, which has high detection efficiency for high energy gamma rays. The energy resolution against the 4.44 MeV gamma-ray from a ^{241}Am-^{9}Be source was measured and it was 6% for the full energy peak [9-10]. The scintillation decay time, measured by injection of a laser light, was 49 ns, fast enough to accept the counting rate capability higher than 10^6 Hz, in the pulse counting spectroscopic mode [10].



(a) *(b)*

Fig. 2 (a) The neutron sensitivity of Ce:LSO per unit volume estimated from nuclear reaction cross sections[10]. (b) The neutron induced noise level in a unit volume of Ce:LSO evaluated from the neutron flux in Fig. 1(b) and the sensitivity shown in Fig. 2(a).

The neutron sensitivity of Ce:LSO per unit volume was estimated, as

$$S = \frac{\left[\sum_{i,j} \int^{T} \sigma_{i,j} N_i(0) \phi \left\{ 1 - \exp\left(-\lambda_{i,j} t\right) \right\} dt \right]}{\phi T} \qquad (1)$$

Here $\sigma_{i,j}$, $N_i(0)$, $\lambda_{i,j}$, ϕ, T denote the *j-th* nuclear cross section of the *i-th* nucleus emitting energetic charged particles, initial atom number of the *i-th* atomic component of Ce:LSO, the decay constant of the product, the neutron flux and a measurement time, respectively. The results are shown in Fig. 2(a). The validity of this estimation was tested experimentally, by measuring the absolute neutron response of Ce:LSO to DD neutrons at the Fusion Neutron Source Facility of JAEA [10].

Then, the neutron-induced noise was estimated by

$$R = \int_0^{\infty} S(E) \cdot \phi(E) dE \qquad (2)$$

where $S(E)$ is the neutron sensitivity estimated by Eq. (1) at the neutron energy E and $\phi(E)$ is the neutron flux at the energy E. The noise level obtained was $\sim 10^{9}$ counts

$cm^{-3}s^{-1}$, as shown in Fig. 2(b). Here, it can be seen that neutrons in the MeV region are responsible to the noise production; nevertheless the major neutron flux is in the lower energy region.

4. Discussions and Summary

The neutron induced noise, estimated from the neutron flux at the detector location, and neutron sensitivity showed the noise level is higher than the acceptable level of the spectroscopic measurement by $\sim 10^3$, even if a $1 cm^3$ detector is used. The electron-photon transport code, EGS4, shows that at least 10 cm^3 volume is required for efficient detection of 4.44 MeV gamma's[10]. In the present neutron transport study, it was found that a half of the neutron comes through the port material, and a half through the port plug. The preliminary study shows that the former could be drastically reduced by LiH in a colimator and the latter by Boron contamination in stainless steel. Further optimization is needed to moderate the neutron spectra and to attenuate neutrons.

Acknowledgment

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