Nuclear Materials and Energy 16 (2018) 207–211

Contents lists available at ScienceDirect

Nuclear Materials and Energy

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

Investigation on A-FNS neutron spectrum monitor system

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ARTICLE INFO

Keywords:
A-FNS
Neutron spectrum measurement
Activation foil
Dosimetry cross section

ABSTRACT

We proposed the neutron spectrum measurement system for Advanced Fusion Neutron Source (A-FNS). It is configured with fission chambers, Self-Powered Neutron Detectors, neutron activation systems using water flow, and activation monitors. In this study, we mainly investigated the multiple activation foils which are sensitive to high energy neutrons. We selected 14 main dosimetry threshold reactions based on specific A-FNS usage conditions. The reactions are as follows: ^{55}Mn(n,2n)^{54}Mn, ^{59}Co(n,p)^{59}Fe, ^{59}Co(n,2n)^{58}Co, ^{59}Co(n,3n)^{57}Co, ^{75}As(n,2n)^{74}As, ^{89}Y(n,2n)^{88}Y, ^{93}Nb(n,2n)^{92m}Nb, ^{169}Tm(n,2n)^{168}Tm, ^{169}Tm(n,3n)^{167}Tm, ^{197}Au(n,2n)^{196}Au, ^{197}Au(n,3n)^{195}Au, ^{209}Bi(n,3n)^{207}Bi, ^{209}Bi(n,4n)^{206}Bi, and ^{209}Bi(n,5n)^{205}Bi. The dosimetry reaction rates were calculated using Monte Carlo code MCNP-5.15 with McDeLicious-11 and nuclear data libraries FENDL-3.1c, IRDFF-1.05 and EAF-2010. As for neutron-induced cross section data of the reactions in the high energy region, we clarified that there were limited experimental data, and proposed new experiment for their evaluations.

1. Introduction

Irradiation experiment on fusion reactor materials is to be conduct under similar neutron irradiation environment to the fusion DEMO reactor. Now, the design activities have been going on the high intense neutron source facility, Advanced Fusion Neutron Source (A-FNS), in Japan toward the early realization of the neutron source operation [1].

In order to evaluate the neutron damage (displacement per atom, DPA) and He-4 production in the test specimen in the test module installed in A-FNS, we have to evaluate the neutron spectrum in the specimen. For the incident neutron spectrum evaluation, the neutron spectrum monitor should be installed in front of the test specimen. In addition, during normal operation of A-FNS, those are required to be assessed with 10% precision level by neutronics calculations and measurements of the neutron spectrum.

In this study, we investigate basic components for the A-FNS neutron spectrum monitor system. In particular, we examine the multiple activation methods in these components, and clarify the concerns.

2. A-FNS neutron spectrum

A-FNS produces a broad peak of D-Li reaction neutrons with a maximum energy up to 55 MeV. A beam footprint of the neutron is 20 cm in width and 5 cm in height. Fig. 1 shows calculated A-FNS neutron spectrum behind the back plate of lithium target using a Monte Carlo code McDeLicious-11 [2], which is an extension to the MCNP5 [3], and the latest fusion evaluated nuclear data library FENDL-3.1c [4]. The percentages of the neutron flux in each energy region, 10^{-6}–10^{-3}, 10^{-3}–1, 1–10, 1–20, and 20–55 MeV, are shown in the figure. The striking characteristic of neutrons produced in A-FNS is a large amount of high energy neutrons above a few MeV over 70%. The back plate is located between lithium target and high flux test module (HFTM) which is dedicated to the irradiation characteristic study on RAFM steels to be tested in the various temperature ranges.

The neutron irradiation damage, DPA, and the He-4 production in the test specimens in HFTM are most critical experimental parameter in the neutron irradiation experiment in A-FNS, and these are required to be estimated with high accuracy. However, there is no way to measure the He-4 contents and the DPA in the irradiated material with high precision level. Thus we are to estimate these values by neutronics calculations and measurements of the neutron spectrum. We are to install the neutron spectrum monitor in front of the HFTM or inside one.

Fig. 2 shows DPA and He-4 production cross section of ^{56}Fe. The DPA and He-4 production have sensitivities to the high energy neutrons as shown in this figure. For high precise assessment of DPA and He-4 production, the high energy neutron spectrum with high accuracy should be measured using the monitor system.

3. Basic components of A-FNS neutron monitor system

The A-FNS neutron monitor system consists of online detection system and offline one. The online detection system mainly combines

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https://doi.org/10.1016/j.nme.2018.06.022
Received 12 December 2017; Received in revised form 11 June 2018; Accepted 29 June 2018
Available online 20 July 2018

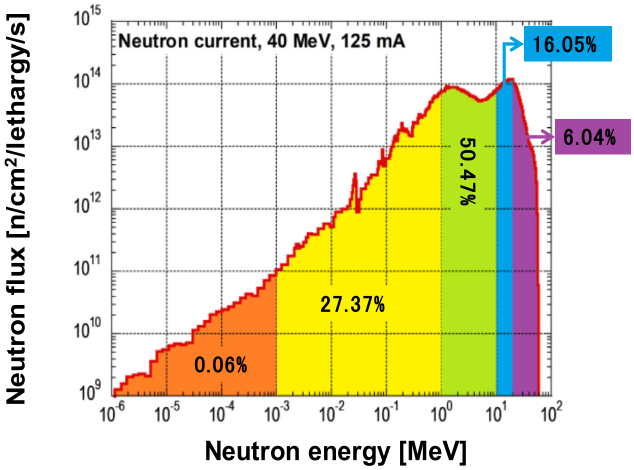

Fig. 1. Calculated A-FNS neutron spectrum behind the back plate.

fission chambers, non-fission chambers, Self-Powered Neutron Detectors (SPNDs), and a water activation. Table 1 summarizes the basic configurations of the system. The fission chamber, which is coated ^{235}U, can measure for entire neutron spectrum due to its high and broad sensitivity. For fast neutrons, various fission chambers have been discussing not only a ^{238}U coating fission chamber but also ^{232}Th, ^{237}Np coating fission chambers. In addition, the dummy fission chamber without fissile material, which has the same structure as the fission chamber without fissile or fertile materials coating, is installed with the fission chambers to compensate γ-ray effect like as fusion power diagnostic system in ITER [5,6]. The other online detection system is the SPND. SPND are commonly used as in-core neutron flux monitor in nuclear power reactors. The emitter materials for the SPND installed in our system are being investigated for high sensitivity of fast neutrons. Note that SPND will install to supplement the main online monitors due to its poor time response. The water flow system in the Test Cell (TC) is actively considering as the online neutron yield monitor. However, the water flow system should be designed with the safety view point such as a double structure of the system, a separated compartment near the system to avoid any chance of contact with lithium.

The neutron spectrum distribution on the beam footprint and in the TC can be mapping using the activation foil/wire/ball as the offline neutron detection in any operation scenarios that without the specimen for neutron source characteristic, and with the specimen for guarantee of the incident neutron spectrum to the specimen. It is directly served a function in the precise assessment of DPA and He-4 production. As described with its detection type, "offline", these activation detectors are generally analyzed and evaluated after the irradiation campaign. On the other hands, we adopt a pneumatic tube as an activation probe transport system to measure using short-lives the daughter nuclides, and to evaluate the measured data promptly after the end of the irradiation campaign. Several pneumatic tubes are prepared for corresponding with various stay times in the TC, in front of HFTM and near the irradiation specimen in the HFTM as far as A-FNS TC design circumstances permit.

4. Activation monitor for A-FNS

We mainly investigate activation monitor for A-FNS. We are to apply the activation method using threshold reactions, (n,p), and (n,xn) reactions, as the activation monitor. We have designed the monitor using multiple activation foils sensitive to high energy neutrons above a few MeV. Table 2 shows the activation foils, their dosimetry reactions and threshold energy, the half-life of the daughter nuclide, the energy of decay photons from the daughter nuclide. We have selected 14 dosimetry reactions based on the following conditions: (a) The reaction elements are monoisotopic or mononuclidic to avoid unnecessary isotopes production. (b) The daughter nuclides emit photons with sufficient intensity for a good detection accuracy. (c) The daughter nuclides have long half-life above a few days. (d) There is the evaluated nuclear data library for the reactions. The reaction rates of the dosimetry reactions were estimated using McDeLicious-11 and nuclear data libraries FENDL-3.1c, International Reactor Dosimetry Fusion File, IRDFF-1.05 [7] and European Activation File, EAF-2010 [8]. The calculation model is shown in Fig. 3. It is modified from the model used in IFMIF design, "mdl 69 [9]". Two beam lines were reduced to one beam line to adjust to A-FNS design. The neutron spectrum monitor is located between the back plate and irradiation field to evaluate incident neutron spectrum.

Fig. 4 shows the reaction rate spectrum as a function of the neutron energy at the neutron spectrum monitor position in the TC for the selected 14 dosimetry reactions. Table 2 shows the evaluable energy range by each dosimetry reaction. We are to measure the neutron flux for different energy range by using 14 dosimetry reactions. The neutron spectrum is determined with the measured reaction rates of the reactions using an unfolding code [10,11]. Some reactions cover the same energy range such as Mn, As, Y, and Nb. Hence, Niobium has a high possibility to use for the range due to its lots of applications and small amounts of uncertainties for nuclear data issue. However, the time schedules such as beam operation, exchange components and maintenance periods for A-FNS are not determined yet, a sudden and an unexpected incident can be occurred. In such cases, the time to prepare

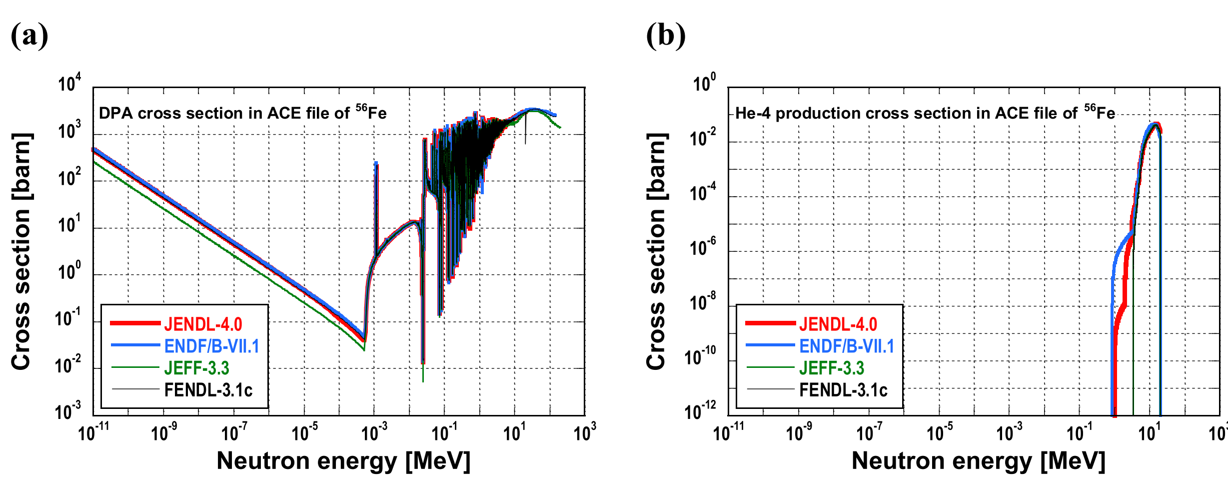

Fig. 2. (a) DPA cross section, (b) He-4 production cross section of ^{56}Fe.