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# Activation analysis of coolant water in ITER blanket and divertor

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ABSTRACT

Coolant water in blankets and divertor cassettes will be activated by neutrons during ITER operation. $^{16}$N and $^{17}$N are determined to be the most important activation products in the coolant water in terms of their impact on ITER design and performance. In this study, the geometry of cooling channels in blanket module 4 was described precisely in the ITER neutronics model 'Alite-4' based on the latest CAD model converted using MCAM developed by FDS Team. The $^{16}$N and $^{17}$N concentration distribution in the blanket, divertor cassette and their primary heat transport systems were calculated by MCNP with data library FENDL2.1. The activation of cooling pipes induced $^{17}$N decay neutrons was analyzed and compared with that induced by fusion neutrons, using FISPACT-2007 with data library EAF-2007. The outlet concentration of blanket and divertor cooling systems was $1.37 \times 10^{10}$ nuclide/cm$^3$ and $1.05 \times 10^{10}$ nuclide/cm$^3$ of $^{16}$N, $8.93 \times 10^6$ nuclide/cm$^3$ and $0.33 \times 10^5$ nuclide/cm$^3$ of $^{17}$N. The decay gamma-rays from $^{16}$N in activated water could be a problem for cryogenic equipments inside the cryostat. Near the cryostat, the activation of pipes from $^{17}$N decay neutrons was much lower than that from fusion neutrons.

## 1. Introduction

The coolant water inside blankets and divertor cassettes of ITER will be activated by neutrons with energies up to 14 MeV. Various reactions will be triggered in hydrogen and oxygen producing radioactive isotopes such as $^{3}$H, $^{16}$N, $^{17}$N, $^{19}$O, etc. Of these $^{3}$H and $^{19}$O are negligible because of their weak decay products and low production. $^{16}$N will induce heat enhancement in cryogenic equipments and exposure dangerous for workers and sensitive equipments outside the biological shield [1]. $^{17}$N will cause activation problems for the cooling pipes and may influence the necessary hands-on maintenance operations. Analysis for $^{16}$N and $^{17}$N concentration distribution in blankets, divertor cassettes and their Primary Heat Transport Systems (PHTS) are critical for ITER design and shielding requirements.

In this study, the following tasks were accomplished to calculate the concentration distribution of $^{16}$N and $^{17}$N and activation of pipes:

(a) Incorporate the detailed No. 4 blanket model with coolant water into the latest ITER reference neutronics model Alite-4 [2].
(b) Calculate the $^{16}$N and $^{17}$N production rates throughout the No. 4 blanket and one divertor cassette.
(c) Calculate $^{16}$N and $^{17}$N concentration distribution in blanket, divertor cassette, and their PHTS.
(d) Study the residual activity of cooling pipes caused by primary and secondary neutrons.

The coolant water in the inlet pipes of blankets and divertors was assumed to be pure water, without $^{16}$N and $^{17}$N. The water density was supposed constant (0.959 g/cm$^3$ in blankets and divertors, 0.916 g/cm$^3$ in their PHTS corresponding to 100–150 °C coolant temperature [3]). Only two competitive processes were considered for the change of radionuclides concentration along cooling pipes: decay and production induced by neutrons. For the production, only the threshold reactions $^{16}$O (n, p) $^{16}$N ($E_{\text{threshold}} \sim 10$ MeV) and $^{17}$O (n, p) $^{17}$N ($E_{\text{threshold}} \sim 8.36$ MeV) were considered.

Results indicate that the decay gamma-rays from $^{16}$N in activated water could be a problem for cryogenic equipments inside the cryostat. The activation of pipes near the cryostat induced by $^{17}$N decay neutrons was much lower than that induced by fusion neutrons.

## 2. Methods and tools

The model updating and modification was conducted by MCAM [4–8]. Neutron transport was accomplished by MCNP [9] with data

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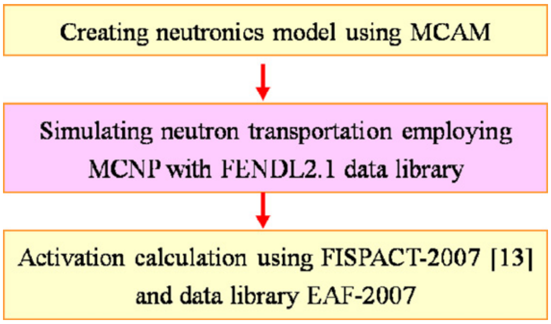


**Fig. 1.** Flow chart of calculation for cooling pipes activation induced by second neutrons [13].

library FENDL 2.1 [10]. The following continuity equation was used to calculate the concentration:

$$\frac{dN}{dt} = R - \lambda N \qquad (1)$$

where $N$ is the number of $^{16}$N (or $^{17}$N) atoms, $R$ is the production rate which was calculated using track length flux estimator (F4) tallies and appropriate normalization (using tally multiplier, FM cards) in MCNP simulation of neutron transportation, $\lambda$ is the decay constant (the half-life of $^{16}$N is 7.13 s and 4.17 s of $^{17}$N), $t$ is the time.

Based on conservative interpretation of the ITER "alternative scenario", the activation of cooling pipes induced by primary neutrons and secondary neutrons emitted in $^{17}$N decay was calculated using R2S method [11,12]. The calculation procedure is shown in Fig. 1.

The work was carried out under the multi-functional 4D neutronics simulation system VisualBUS [11,14–16] developed by FDS Team.

## 3. Neutronics models

### 3.1. The Alite-4 model

Alite-4 is a three-dimensional ITER tokamak MCNP model of 40° in toroidal direction with vertical reflecting bounded planes on both sides. It includes major components such as the magnet coils, the central solenoid, the cryostat, the vacuum vessel, the divertor cassettes, the blanket modules and the upper, equatorial and lower ports.

However, in the Alite-4 model, blankets and divertors are modeled roughly, filled with mixtures of stainless steel and water (see Fig. 2). The cooling channels are not described. Therefore updating is needed for the blanket and divertor cassette modules in Alite-4 model.

### 3.2. Updating and modification

The detailed No. 4 blanket neutronics model was created by MCAM based on the CAD model provided by ITER IO. It consisted of first wall, shield block, and the coolant water (see Fig. 3). The model of coolant water was divided into 16 sections along the flow path, each having different neutron flux values, water velocities and residence times. The detailed No. 4 blanket model was then incorporated into the Alite-4 model (see Fig. 4).

The divertor cassette consists of a cassette body, inner target, outer target and dome. In this work, the sections of divertor in Alite-4 were divided into cells with dimension of 15 cm × 10 cm × 5 cm. For one divertor cassette, the cell number was increased to 1400 from 122.

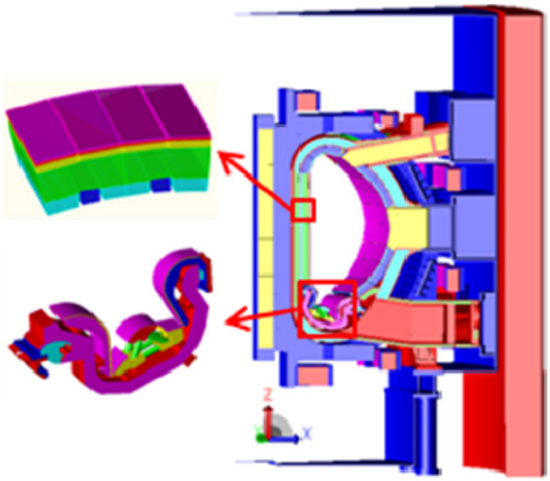
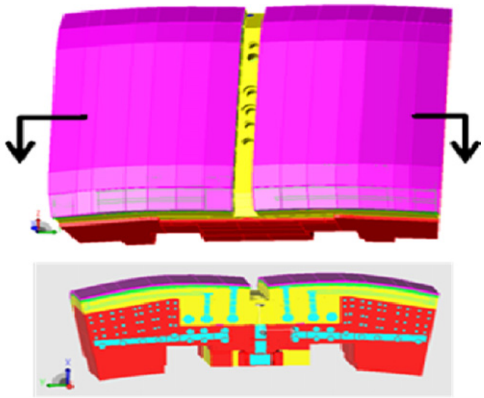


**Fig. 2.** Blanket and divertor cassette in Alite-4.

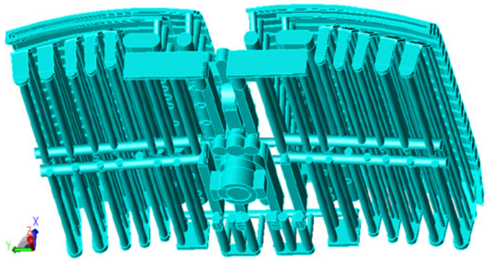
## 4. Calculations and analyses

### 4.1. $^{16}$N and $^{17}$N analyses in blanket PHTS

The selected cooling proposal for blankets was that coolant water flows from shielding block to first wall. Using the updated Alite-4 model and a neutron emission corresponding to 500 MW fusion power, the $^{16}$N and $^{17}$N production rates inside the No. 4 blanket module were calculated. The concentration in each part of the coolant water was obtained by solving the continuity equation (Eq. (1)). In each region, the initial value of $^{16}$N (or $^{17}$N) concentration was supposed equal to the outlet concentration of the previous region of the path. The total water flow rate of the No. 4 blanket



(a) Neutronics model



(b) Coolant water

**Fig. 3.** Detailed model of No. 4 blanket.