Performance Evaluation of Neutron Absorption Materials with Temperature Change

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1. Introduction

With the necessity of controlling and shielding neutrons, a variety of neutron absorption materials have been used in the radiation facilities such as nuclear reactor, Neutron Transmutation Doping (NTD) service company, and so on. Some of these facilities are operated at higher than room temperature, thus the neutron absorption material can be directly affected by the surrounding environment where the temperature is not maintained in a constant condition. Meanwhile, a nucleus in an atom is continuously vibrated with the thermal energy, after which there arises a range of relative speeds between a neutron and the nucleus, even for a fixed neutron speed. At higher temperature, the random motion of the nucleus reproduces new resonance with a lower and broader peak, i.e., Doppler broadening of a resonance, and the capture cross-section of neutron is revised. Therefore, the performance of neutron absorption materials may vary with a change of temperature.

In this study, the absorption abilities of three kinds of neutron absorbers generally used in the reactor core were analyzed at a range of temperatures from 293.6K to 584K. The makxsf code [1] was used to create the temperature-dependent neutron cross-section libraries based on ENDF/B-VII, and the neutron flux calculations for the absorption materials were performed using the MCNP6 code [2].

2. Materials and Methods

Boron Carbide (B_4C), Gadolinia (Gd_2O_3), and Silver-Indium-Cadmium alloy (Ag-In-Cd), which are generally used for neutron control materials in a pressurized water reactor (PWR), were chosen for assessment. **Table 1** shows a specification above mentioned materials, which include the density, atomic compositions.

In this study, the range of temperature is considered with a reference to Korean Nuclear Power Plant (NPP), for instance, the moderator temperature at the hot full power (HFP) is increased to 584K. Therefore, the 6 different points of temperature with an interval of 50K was chosen; 293.6K, 343K, 393K, 443K, 493K, 543K, and 584K. To produce the temperature-dependent neutron cross section libraries, the makxsf code was used based on ENDF/B-VII data.

The change of absorption ability was analyzed through MCNP calculations applied with new generated cross-section libraries. A dimension of the neutron absorption materials was assumed to be 200cm $\times$200cm with a thickness of 0.01cm. Because these

Table 1 Specification of Neutron Absorber Materials

Neutron Absorber	Density [g/cm^3]	Nuclide	Weight Fraction [%]	Neutron Absorber	Density [g/cm^3]	Nuclide	Weight Fraction [%]
B_4C	2.51	^{10}B	15.574	Ag-In-Cd	7.41	^{107}Ag	41.471
		^{11}B	62.686			^{109}Ag	38.529
		C (Nat.)*	21.740			^{113}In	0.644
Gd_2O_3	10.27	^{152}Gd	0.174			^{115}In	14.357
		^{154}Gd	1.891			^{106}Cd	0.063
		^{155}Gd	12.840			^{108}Cd	0.045
		^{156}Gd	17.760			^{110}Cd	0.625
		^{157}Gd	13.578			^{111}Cd	0.640
		^{158}Gd	21.551			^{112}Cd	1.207
		^{160}Gd	18.966			^{113}Cd	0.611
		^{16}O	13.209			^{114}Cd	1.437
		^{17}O	0.032			^{116}Cd	0.375

* Natural Carbon

materials have been generally used for absorbers for thermal neutrons, in this study, a point neutron source of a mono energy (0.025 eV) with isotropic emission was assumed to be located 100cm away from the target. Neutron flux was detected at a point of 5cm away from the target material, and F5 tally in MCNP was used in the calculations. All calculation results were normalized to that at the room temperature of 293.6K.

3. Results and Discussions

A series of calculations for the analysis of neutron absorption ability were performed with the three kinds of materials. The relative errors in each calculation, which correspond to one standard deviation, were shown to be 0.02% (B_4C), 0.01% (Ag-In-Cd), and 0.02% (Gd_2O_3), relatively. The effects of temperature on neutron absorption ability were presented in **Figure 1-3**. In the case of B_4C, even though the change of the neutron flux is not significant, those at other temperatures were slightly decreased with reference to that at room temperature. In addition, the Ag-In-Cd material represents similar trend with that of B_4C.

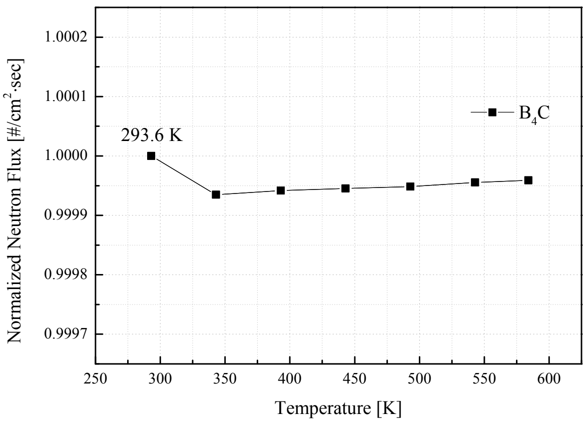

Fig. 1 Effect of Temperature on Neutron Penetration for B_4C Absorber

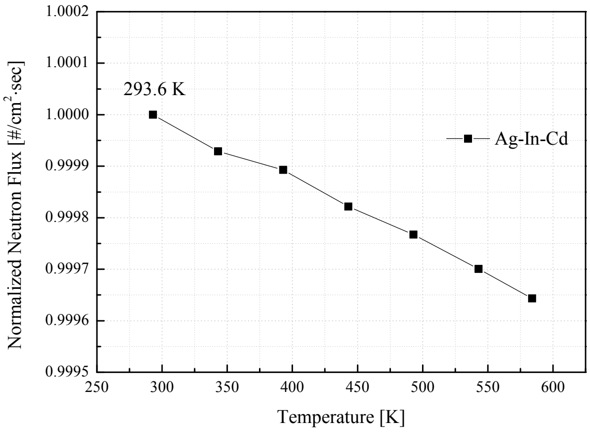

Fig. 2 Effect of Temperature on Neutron Penetration for Gd_2O_3 Absorber

However, the neutron penetration for the Gd_2O_3 absorber represents to be increased with a change of temperature, and the maximum difference shows approximately 3% within the analysis range of temperature. This phenomenon of the Gd_2O_3 absorber seems to be caused by the Doppler broadening of the neutron absorption cross-section, which means the peak of that at the thermal energy (0.025 eV) is also decreased as well as those at the range of other neutron energy.

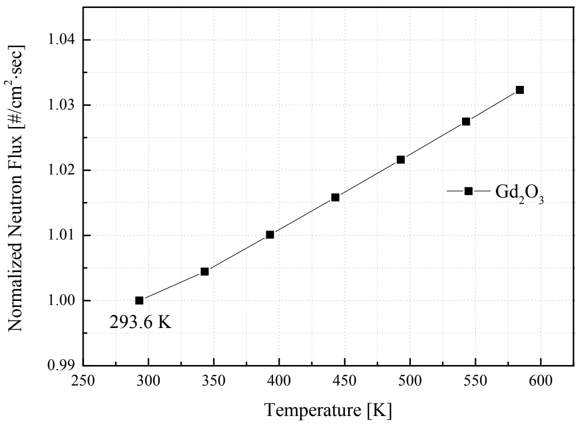

Fig. 3 Effect of Temperature on Neutron Penetration for Ag-In-Cd Absorber

4. Conclusions

The absorption performance for three kinds of neutron absorption materials, i.e., B_4C, Gd_2O_3, Ag-In-Cd, was evaluated at a range of temperature from the room temperature up to 584K. As a result, the neutron absorption abilities for B_4C and Ag-In-Cd do not vary with the change of temperature, while that for Gd_2O_3 absorbers was shown to be decreased approximately 3% with reference to that at 293.6K in the temperature range between the 293.6K and 584K. This phenomenon of the Gd_2O_3 absorber seems to be caused by the Doppler broadening of the neutron absorption cross-section. Therefore, it is expected that the effect of material temperature on the neutron absorption performance is needed to be considered in the design of nuclear reactor and the analysis of radiation shielding.

Acknowledgements

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