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Nuclear Heating Analysis for HANARO Cold Neutron Source by McCARD Burnup Calculations

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1. Introduction

The HANARO research reactor at KAERI has been operated since 1995 for many research purposes such as basic science research using neutron beam, nuclear fuel irradiation test, and development of radioactive isotope. Cold neutrons of about 20K are produced from the cold neutron source (CNS) in the HANARO for cell observation, analysis of the material structure, etc. It is very important to maintain the low temperature of the CNS.

The nuclear heating of the CNS has been analyzed [1] using MCNP [3] and HELIOS [4] by KAERI. The result of the previous study was the 5.8 % increase of the CNS nuclear heating during one cycle operation of 28 days at equilibrium core. The purpose of this study is to ensure the CNS cooling capacity during the cycle operation by McCARD [5] nuclear heating calculations.

2. McCARD Model

Figure 1 shows the McCARD model configuration of the CNS moderator cell. The shape of the CNS moderator cell is a double cylinder with an open cavity. In the moderator cell, liquid hydrogen is used as a cold neutron moderator. The wall thickness of the moderator cell is 1mm and its material is aluminum alloy. The inner cylinder height is 15cm.

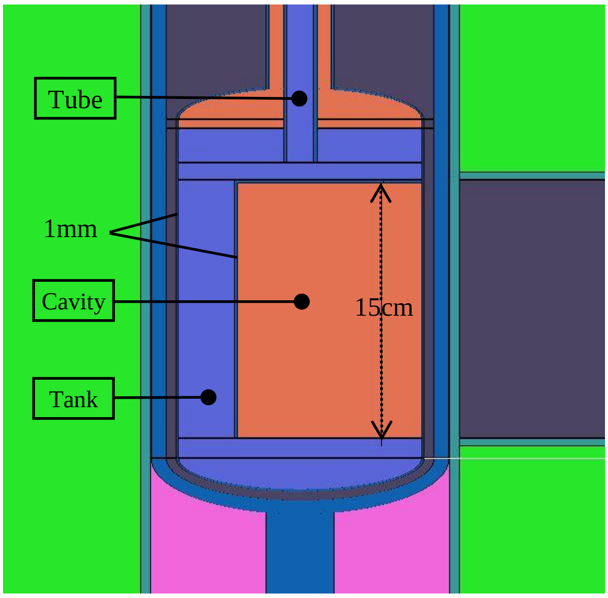

Fig. 1. The cross-sectional view of CNS moderator cell

3. Nuclear Heating Analysis

3.1 Nuclear Heating

The nuclear heat of CNS is generated from various types of heat sources and in this study, four types of heat sources are considered. These are neutron heating by prompt neutron from the fission reaction, gamma heating of prompt gamma ray from the fission reaction and capture gamma, delayed gamma ray from the fission products, and beta heating from the beta decay of Al-28 which is the primary material of CNS [2].

3.2 Conversion Factor

In the particle transport simulation using McCARD, the value of nuclear heating is given after normalization with the number of particles used in the simulation. Hence, the conversion factor is used to convert the given value in the results to a real-scale one.

Table I: Conversion factor used in McCARD

Code		McCARD
Conversion factor		$\dfrac{Q}{\kappa \cdot \sum_{i=1}^{m} \Sigma_f^i \phi_i V_i}$
Power (Q)		29.3 MW
Energy per fission (κ)	U-235	202.3415 MeV
	U-238	212.6019 MeV
Number of fission neutrons per fission (ν)		Energy dependent
Number of fissions per fission neutron ($\sum_{i=1}^{m} \Sigma_f^i \phi_i V_i$)		Energy dependent
Physical meaning		Number of current generation fission neutrons

In the McCARD simulation, the conversion factor calculated during the neutron transport simulation in each burnup step is used. It uses energy per fission (κ) for actinides given in the GRPCX.LIB library file, and fission reaction rate which is calculated in the simulation. In each simulation, the energy dependent fission nu (ν) value obtained from neutron cross section library is used.

According to its definition, the physical meaning of the conversion factor in McCARD is the number of current generation fission neutrons and it is the key factor of the change in CNS nuclear heating.

3.3 McCARD burnup calculations

In the previous study, nuclear heating was calculated under the conditions of the equilibrium core at BOC, MOC, and EOC. The position of control rods was adjusted for each case.

To evaluate the accurate nuclear heating, McCARD burnup calculations are performed in two ways, burnup calculation with constant power and constant flux. The former is the way that the power reactor is operated and the latter is the way that the research reactor is operated.

Table II: McCARD burnup calculation option

Category	Burnup calculation	
Option	Constant power	Constant flux
Calculation option	1,000,000 histories per cycle on 50 inactive and 100 active cycles	
Burnup step	28 days	
Constant value	29.3 MW	5.02×10^{14}

The burnup calculation with constant power is performed with fixed total power which is the actual total power of the HANARO reactor. The value of constant average flux is calculated from the BOC state at 29.3 MW.

4. Calculation Results

4.1 Burnup Calculation with Constant Power

Figure 2 shows the calculation results with constant power. Tables III, IV show the nuclear heating in CNS increased by 4.81 % when the conversion factor increased by 5.04 %.

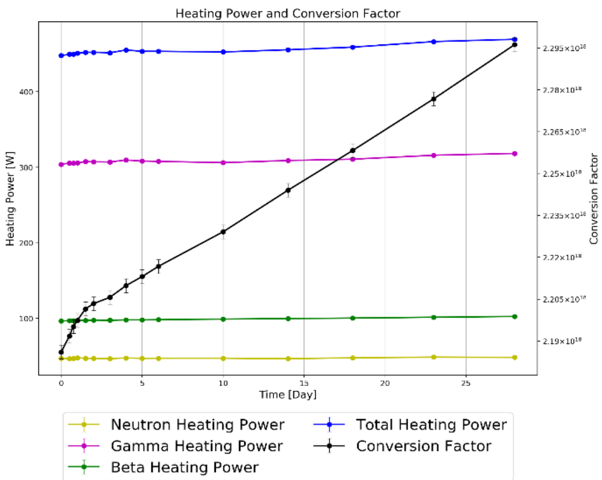

Fig. 2 Nuclear heating power with constant power

Table III: Nuclear heating from each source

-	Neutron heating (SD)	Gamma heating (SD)	Beta heating (SD)	Total heating (SD)
BOC	47.3 W (0.34)	303.9 W (1.94)	96.7 W (0.14)	447.8 W (1.98)
EOC	48.4 W (0.36)	318.3 W (2.05)	102.6 W (0.14)	469.4 W (2.09)
Rel. Diff.	2.39 % (1.05)	4.77 % (0.93)	6.11 % (0.20)	4.81 % (0.64)

Table IV: Conversion factor with constant power

BOC	EOC	Relative Diff.
2.19×10^{18} (2.46×10^{15})	2.30×10^{18} (2.46×10^{15})	5.04 % (0.16 %)

4.2 Burnup Calculation with Constant Flux

Figure 3 shows the calculation results with constant flux. The actual total power of the HANARO reactor decreased by 6.3 % while the reactor average flux level is constant. Tables V, VI show the nuclear heating in CNS decreased by 1.68 % when the conversion factor decreased by 1.48 %.

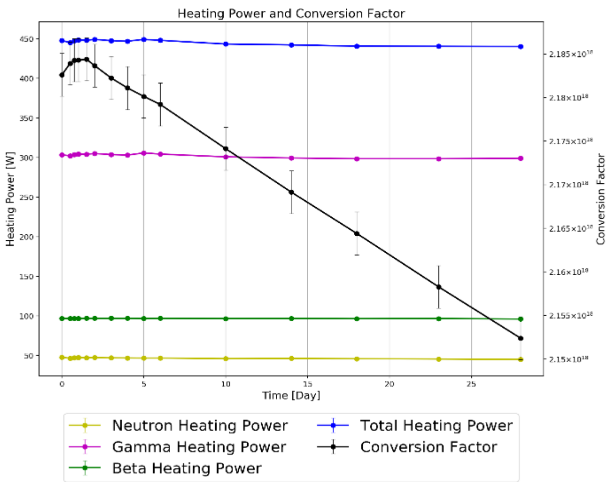

Fig. 3 Nuclear heating power with constant flux

Table V: Nuclear heating from each source

-	Neutron heating (SD)	Gamma heating (SD)	Beta heating (SD)	Total heating (SD)
BOC	47.6 W (0.35)	303.4 W (1.93)	96.6 W (0.14)	447.7 W (1.97)
EOC	45.0 W (0.33)	299.0 W (1.94)	96.1 W (0.14)	440.1 W (1.97)
Rel. Diff.	- 5.47 % (1.01)	- 1.46 % (0.90)	- 0.52 % (0.20)	- 1.68 % (0.62)

Table VI: Conversion factor with constant flux

BOC	EOC	Relative Diff.
2.18×10^{18} (2.46×10^{15})	2.15×10^{18} (2.46×10^{15})	- 1.48 % (0.16 %)

5. Conclusions

The nuclear heating of HANARO CNS is analyzed by McCARD considering nuclear heating by the neutron, gamma, and beta. The physical meaning of the conversion factor is precisely reviewed and the accurate conversion factor calculated by McCARD neutron transport simulation is used. McCARD burnup calculations used the equilibrium core in two different conditions; the constant power and the constant average flux. The nuclear heating in CNS at the EOC core is increased by 4.81 % compared with the BOC core in the constant power condition and decreased by 1.68 % in the constant average flux condition. The constant flux condition is more appropriate results for a real simulation because the HANARO is actually operated in the constant flux condition.

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