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

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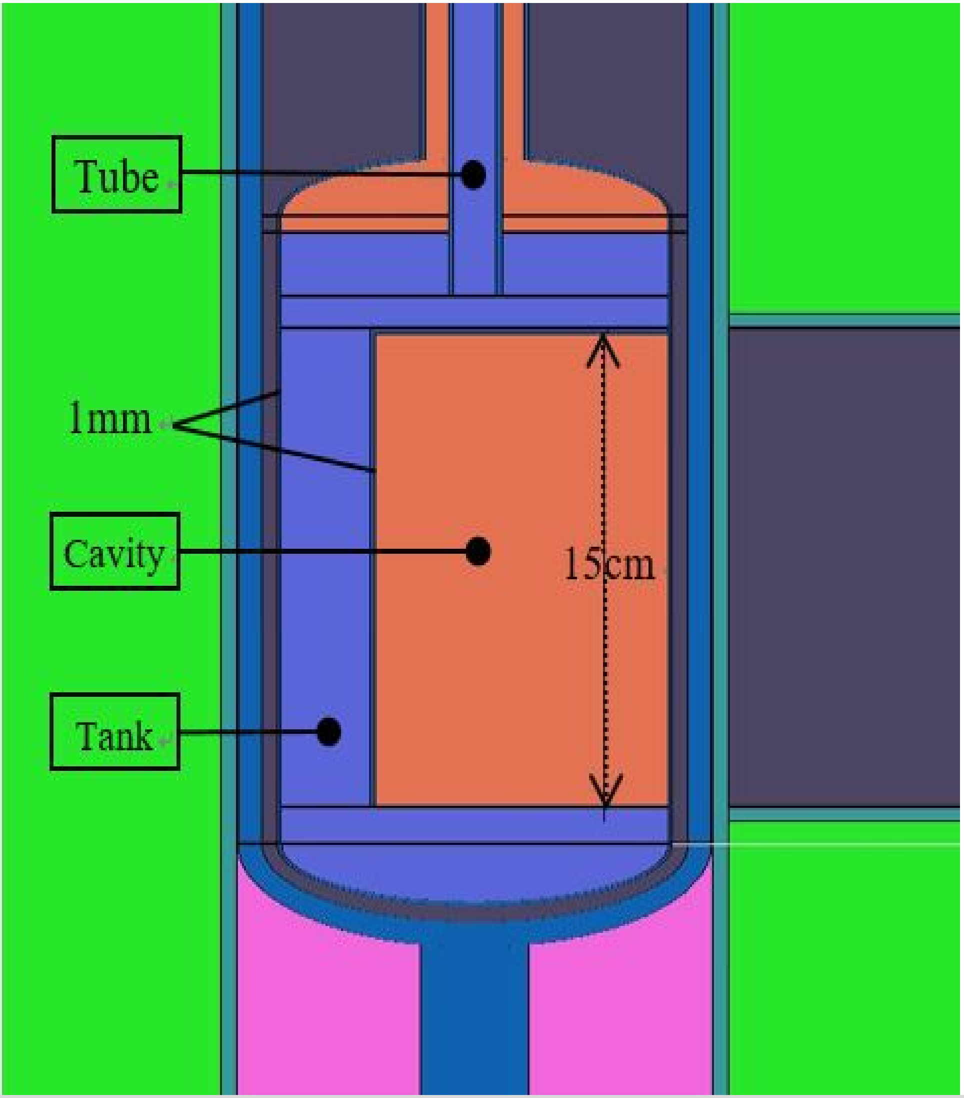
Contents

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.
- The nuclear heating of the CNS has been analyzed using MCNP and HELIOS 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 nuclear heating calculations.

CNS

- The cross-sectional view of CNS



- A double cylinder with an open cavity.
- In the moderator, liquid hydrogen is used as a cold neutron moderator.
- The wall thickness of the moderator is 1mm and its material is aluminum alloy. The inner cylinder height is 15cm.

Conversion Factor

- Conversion factor used in McCARD

Code		McCARD
Conversion factor		$\dfrac{Q}{\kappa \cdot \sum_{i=1}^{m} \Sigma^{i}_{f} \phi_i \mathrm{V}_i}$
Power (Q)		29.3 MW
Energy per fission (κ)	U-235	202.3415 MeV
	U-238	212.6019 MeV
Number of fissions per fission neutron ($\sum_{i=1}^{m} \Sigma^{i}_{f} \phi_i \mathrm{V}_i$)		Energy dependent
Number of fission neutrons per fission (ν)		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 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.

Nuclear Heating Analysis

- The nuclear heat of CNS is generated from various types of heat sources.

  - Neutron heating by prompt neutron from the fission reaction.

  - Gamma heating of prompt gamma ray from the fission reaction.

  - Gamma heating of delayed gamma ray from the fission product.

  - Beta heating from the beta decay of Al-28.

    * Neutron capture reaction rate of Al-27 × Negatron kinetic energy from the beta decay of Al-28

McCARD burnup calculation option

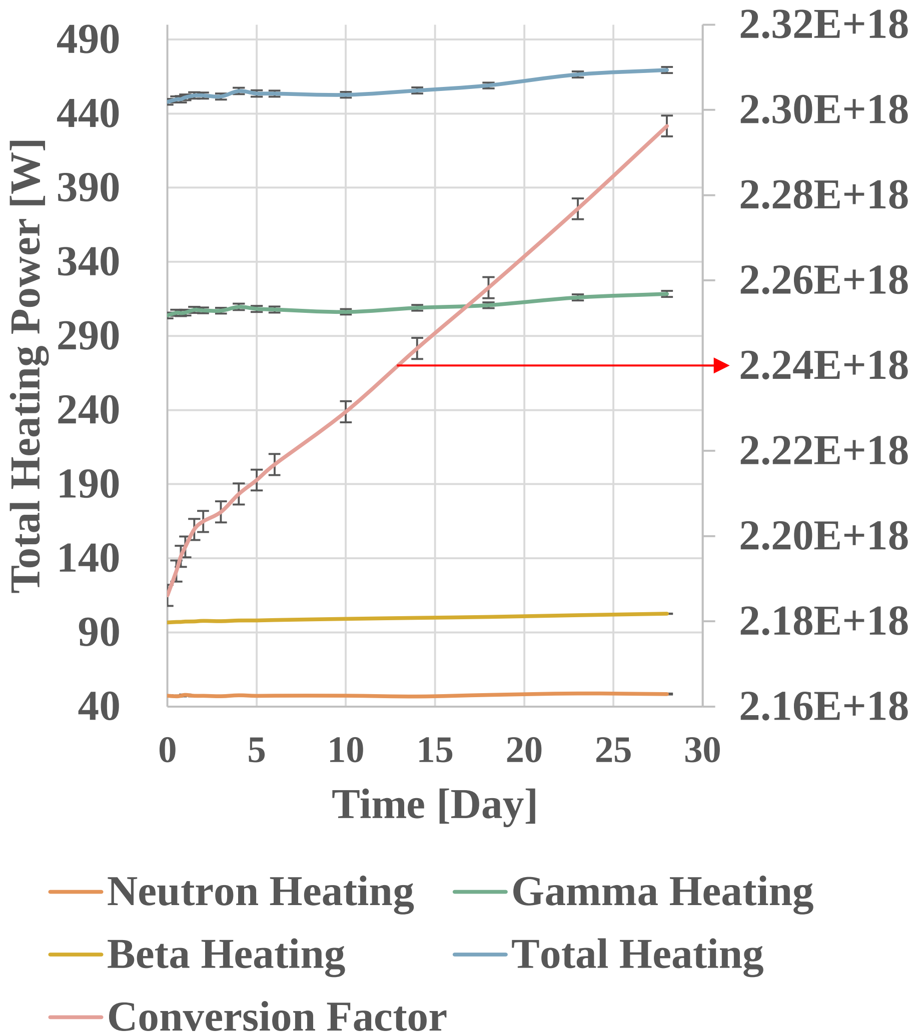
- McCARD burnup calculation option

Category	Burnup calculation	
Option	Constant power	Constant flux
Calculation option	1,000,000 histories per cycle on 50 inactive and 100 active cycles ENDF/B-VII.0	
Burnup step	28 days	
Constant value	29.3 MW	$5.02 \times 10^{14}/cm^2 \cdot s$
Core	Equilibrium core	

* The value of constant average flux is calculated from the BOC state at 29.3 MW

McCARD burnup calculation with constant power

- Heating power and conversion factor



- 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)

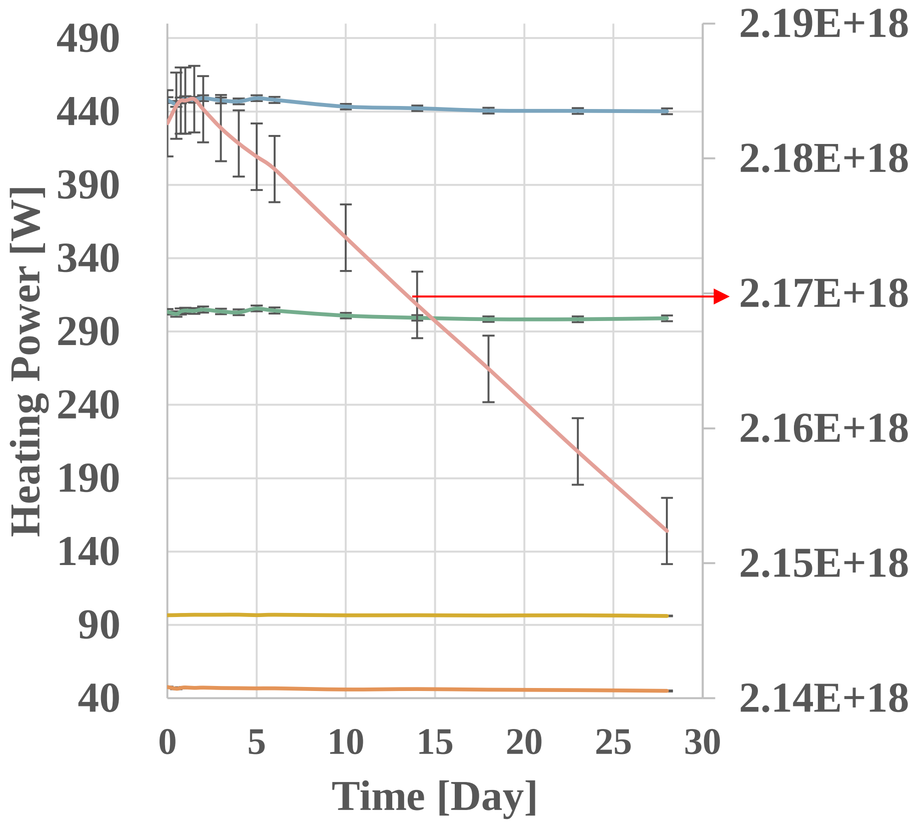
- Conversion factor with constant power

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

- The way that power reactor is operated

McCARD burnup calculation with constant flux

- Heating power and conversion factor



- 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)

- Conversion factor with constant flux

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

- The way that research reactor is operated

Conclusions

- The nuclear heating of HANARO CNS is analyzed by McCARD considering nuclear heating by the neutron, gamma, and beta.
- 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 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 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.